

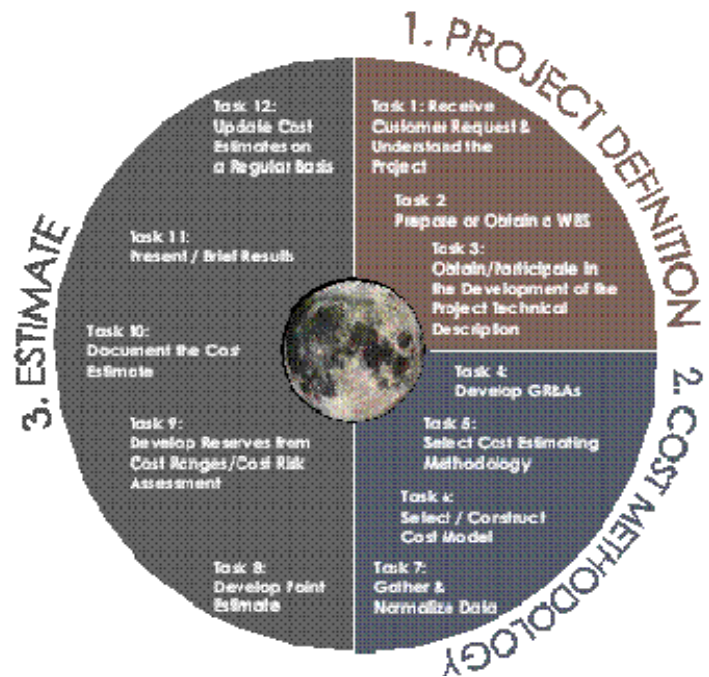
COVER FOR
CORE VOLUME

Cost Estimating Process

This section is the “how to” of the NASA CEH where details on the cost estimating process from start to finish and tips on the iterative nature of the process are found. Shown in the graphic to the right, there are three main parts to the NASA 12 step cost estimating process. In this section, each of the 12 tasks within each of the three parts are described in greater detail.

The first part of the NASA CEH process is Project Definition. This is when the estimator clarifies the reason for the estimate, defines expectations and begins to understand the project that will be estimated. As the estimate is being defined and data is gathered, a Work Breakdown Structure (WBS) and technical description is obtained. This defines the project and forms the foundation for the estimate. As the estimator continues through the estimating process these steps will be revisited as new information is obtained.

As outlined below there are three tasks in Part I of the cost estimating process. These three tasks prepare and define the estimate and the system being estimated.



Part I: Project Definition

Task 1: Receive Customer Request and Understand Project

Task 2: Build or Obtain WBS

Task 3: Obtain / Participate in Development of Project Technical Description

Part II of the cost estimating process includes four tasks that create the approach and framework for the estimate. The Ground Rules and Assumptions will be the most revisited Task in this Part of the process. As methodologies are selected and the data is gathered the ground rules and assumptions, methodologies and even the cost model may be refined as appropriate.

Part II Cost Methodology

Task 4: Develop Ground Rules and Assumptions

Task 5: Select Cost Estimating Methodology

Task 6: Select / Build Cost Model

Task 7: Gather and Normalize Data

Part III of the cost estimating process has five tasks that include the actual conduct, presentation and maintenance of the cost estimate. All of these tasks are important in their own right. Together they become critical for a defensible and complete estimate.

Part III: Estimate

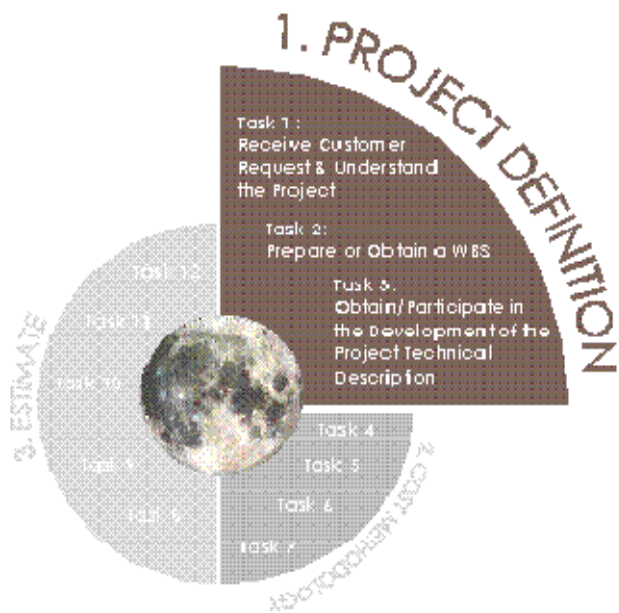
Task 8: Develop Point Estimate

Task 9: Develop and Incorporate Cost Risk Assessment

Task 10: Document Probabilistic Cost Estimate

Task 11: Present Estimate Results

Task 12: Update Cost Estimate on a Regular Basis



4.1 Part 1: Project Definition Tasks

The first three tasks in the cost estimating process relate to defining the project. The tasks associated with defining the project help to establish the framework from which the estimate can be conducted.

Task 1: Receive Customer Request and Understand the Project

The goal of this task is to interface sufficiently with the customer to gather enough project information to generate an accurate estimate.

There are three activities associated with understanding the project.

1. Gather all relevant project data for evaluation. Discuss schedule, data, expectations, and resource requirements with the requesting customer. If an estimate has been conducted for this product before, review and incorporate lessons learned and customer feedback from the last effort.
2. Evaluate the project's mission needs, objectives, and goals and assess the operating environment and life cycle phase for the project within the context of the NASA enterprise architecture.
3. Review all related project documentation, including an existing technical baseline or CADRe, previous estimates, budget data and programmatic data such as schedules.

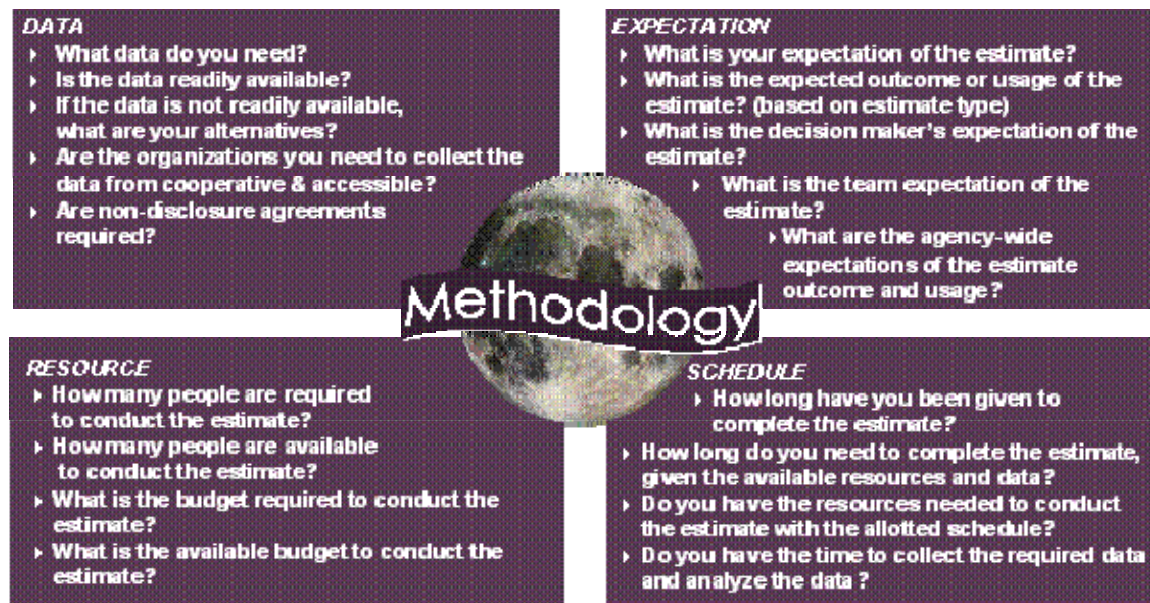


Exhibit 5-1
The Four Critical Elements of a Cost Estimate

When a request for a cost estimate is received, the supervisor of the cost group must ascertain if he/she has the resources to accept the assignment based upon his/her understanding of the expectations of the estimate. The estimator then determines the magnitude of the workload required, i.e., the type of estimate, the due date(s), and relative priority of the request. If the request is accepted, the supervisor will notify the requester of this fact and will assign an estimator (or estimators) to the task. As illustrated in Exhibit 5-1, there are four critical elements to any estimate that need to be understood and agreed upon between the cost estimator and the decision-maker before a methodology can be chosen and an estimate can be developed. These four elements are resources, data, schedule and expectations.

While the methodology selected will be influenced by these four elements, the estimating process itself does not vary greatly between the different types of estimates.

It is essential that the cost estimating process begins on the right footing, which is why this first task is important. In early life cycle phases, there will be many unknowns. It is the role of the cost estimator to ask insightful questions that help the Project Management staff make decisions regarding key aspects not normally considered in an early stage (e.g., maintenance concept, testing strategy, etc.) and to address issues such as manpower, schedule, technologies, and cost drivers that can have a major impact on risk.

Task 2: Build or Obtain a WBS

The objective of this task is to provide a consistent structure that includes all elements of the project the cost estimate will cover.

Determining the four critical elements of a cost estimate along with understanding the initial need and the desired outcome of the estimate are essential to starting an estimate off on a solid foundation. This initial communication and understanding will provide the estimate with adequate resources, funding and support for a successful outcome.

There are three activities associated with preparing or obtaining a WBS:

1. Determine if a WBS exists or work with the project to create.
2. Create a WBS Dictionary to define the WBS elements.
3. Ensure that the cost estimating WBS is consistent between functions such as budgeting, weight statements, EVM, project plan, System Engineering Master Plan (SEMP), contracts, Integrated Financial Management (IFM), etc., to enable improved cost estimation, future data collection, and performance measurement and management.

According to NPR 7120.5x, the WBS “serves as the structure for project technical planning, scheduling, cost estimating and budgeting, contract scope definition, documentation, product development, and status reporting and assessment (including integrated cost/schedule performance measurement).” The WBS is a critical project management tool used throughout the project’s life cycle to structure the project, to manage acquisitions, to capture all costs, and to communicate scope among review authorities and stakeholders. It provides a structure that includes all elements of the project the cost estimate will cover.

In Pre-Phase A, the cost estimator will either obtain a high-level Project WBS(s) from the project staff or work with them to develop one. A Project WBS is the comprehensive WBS including all life cycle phases and items including the hardware for the product, and other items such as training, SE&I, I&T, system test, and project management. Additionally, a companion high-level WBS dictionary that describes the overall structure and content of each major element of the WBS must be developed. The WBS dictionary communicates the contents of each major WBS element to avoid duplication and to ensure full coverage.

A good WBS has a strong product focus with a project life cycle orientation, and generally includes hardware, software, and supporting services. It establishes a hierarchical structure or product oriented "family tree" of elements. It is used to organize, define and graphically display all the work items or work packages to be done to accomplish the project's objectives, including:

- ▶ Project and technical planning and scheduling;
- ▶ Cost estimation and budget formulation (in particular, costs collected in a product-based WBS can be compared to historical data collected against the same products);
- ▶ Defining the scope of statements of work and specifications for contract efforts;
- ▶ Project status reporting, including schedule, cost, workforce, technical performance, and integrated cost/schedule data [such as EVM and estimated cost at completion (EAC)]; and
- ▶ Plans such as the SEMP and other documentation products such as specifications and drawings.

It is desirable that WBSs be standard and consistent throughout NASA and during Pre-Phase A and Phase A is the right time to begin creating this standard structure. This means that WBS elements for similar projects within each NASA organization will have standard and consistent labels and definitions (i.e., content) and be standard and consistent across different cost disciplines (e.g., cost estimating, EVM, cost databases, etc.). This consistency will enable

improved cost estimation, performance measurement, and project management. To the extent possible, these WBSs should also be consistent with the WBSs contained in the cost models used at NASA (e.g., NAFCOM, PRICE, SEER, etc.). The NASA Systems Engineering Handbook sets forth policies and processes for preparing WBSs and some standard examples of WBSs used at NASA are listed in Appendix x.

- ▶ MIL HDBK 881B (<http://www.kolacki.com/MIL-HDBK-881.htm>) is the DOD's guide to WBSs
- ▶ The OSD CAIG (<http://www.dtic.mil/pae/paeosg04.html>) provides guidelines for the development and definition of standard elements for O&S cost estimates.
- ▶ A WBS may also be called a Cost Estimating Structure (CES), Cost Element Structure (CES), or Cost Breakdown Structure (CBS).
- ▶ The WBS you create might not necessarily map to the estimating structures found in commercial tools used in the estimating community. Know the tool you plan to use before you begin and be prepared to provide a map of your WBS back to the project WBS if there are differences.
- ▶ Examples of standard WBS's used at NASA can be found in Appendix x.

Task 3: Build or Obtain a Project Technical Description or CADRe

The objective of this task is to establish a common baseline document used by the project team and independent estimators to develop their estimate(s).

There are two activities associated with developing or obtaining a project technical description:

1. Describe the level two or lower system characteristics, configuration, quality factors, security, its operational concept, and the risks associated with the system for use by the cost estimator.
2. Describe the system's (or the project's) milestones, schedule, management strategy, implementation/deployment plan, test strategy, security considerations, and acquisition strategy.

Every estimate regardless of size needs to define what is being estimated. The NASA organization sponsoring a project will prepare, as a basis for life-cycle cost estimates, a description of features pertinent to costing the system being developed and acquired. The type of document used to record this project technical description depends on the time available to conduct the estimate, the size of the project, technical information available, including the requirements' thresholds and goals (objectives), and the phase of the life cycle in which it exists. Projects that are smaller in size or earlier in their project lives may only require a simple data sheet with technical requirements provided by the project to support developing a ROM cost estimate.

The project technical description defines and provides quantitative and qualitative descriptions of the project characteristics from which cost estimates will be derived. As such, the project technical description ensures that cost projections jointly developed by the Project Offices and the independent review organizations are based on a common definition of the system and project. The project technical description also should identify any area or issue that could have a major

cost impact (e.g., risks) and, therefore, must be addressed by the cost estimator. A further benefit derived from the CADRe is its built-in requirement for end-of-contract actual costs and technical parameters (by WBS element) used to update NASA cost models. These values (e.g., KEPPs) and actual costs at the end of the contract are ported into the ONCE database.

The CADRe is a hybrid requirement that is unique within NASA that combines key elements of two previously used DRDs - the Cost Analysis Requirements Description (CARD) and LCCE into a single, coordinated document. The CADRe, like the CARD, is "owned" by the PM, although populating most of its content can be a contractual requirement. While it does not incorporate the WBS DRD, the information contained in the CADRe DRD must conform to the approved project WBS in order to ensure that each and every element of the entire project is included. See Appendix H for information about the CADRe DRD.

Templates for the NASA CADRe are still in development as of the date of publication for the NASA CEH. When they are available for release, they will be posted on ceh.nasa.gov.

CADRe Overview:

The Cost Analysis Data Requirement (CADRe) documents the programmatic, technical, and lifecycle cost information for a major NASA Project for future use by Project Managers. This is a Project-level requirement.

The CADRe is comprised of three parts:

- Part A contains general descriptive information about the project. The Part A template below provides the necessary guidance.
- Part B contains hardware and software technical parameters necessary to estimate the project's life cycle cost. The Part B template below provides the necessary guidance.
- Part C contains the project's life cycle cost estimate (LCCE). Part C represents the Project's cost estimate and the Project Manager is responsible for collecting the inputs from the various participants including Full Cost elements and submitting an integrated cost estimate.

Many times, in Pre-Phase A, a formal CADRe is not required. However, following the basic format for the NASA CADRe in developing the project technical description for these projects in Pre-Phase A is encouraged. It will help in the eventual development of the CADRe in later life cycle phases when required.

The required data for submission by the Contractor are CADRe Part B spreadsheet technical data required for the Project to complete the full CADRe and some detailed cost data to support Part C. Most of these data will be available through technical documents presented at the PDR, CDR, etc. and cost data provided through NF533 and Contractor Performance Reports. Info:

<http://ceh.nasa.gov/downloadfiles/CADRe.html>

Review and Submission Process

The CADRe process can vary from center to center, but will usually begin with a kickoff meeting between PA&E/CAD, Program Executive, Project Manager, Mission Directorate Cost Focal Point, and IPAO cost analyst(s). This meeting will cover the CADRe requirements and expectations and how the CADRe will be developed.

Support contractors, or Cetner personnel will develop the CADRe from supplied data. The information will populate the three CADRe sections based on the reference material provided by the Project. Typically, a large portion of Part A is assembled from the review material and various

planning documents (Project Plan, Science Management Plan, etc.), while Part B is completed using the Project's mass equipment list (MEL) and power equipment list (PEL). Any additional technical parameters to be included in Part B may be obtained from the review material or other references. Finally, the cost data for Part C is obtained from the Project Business Manager. The structure of this data may vary from project to project, but it should be at a level of detail that allows mapping to the Part C outline found in the CADRe template.

During the process of creating the CADRe document, it is expected that there will be a low level of interaction with the Project Systems Engineer (or similar point of contact) to clarify any issues encountered while creating Parts A, B, and/or C. CADRe Parts A and B will be completed and submitted for Draft Review by center management. The CADRe will then be given to the necessary individuals for any independent cost estimation activities. After the milestone review, Parts A and B may need to be updated slightly to reflect the final design presented and Part C can then be completed with the final project costs.

Center or PA&E staff will review the CADRe for compliance with the CADR templates and make any necessary revision. The revised CADRe will be submitted to the Project Manager for any necessary revisions and approval. Once the PM provides approval and signs, the CADRe will be forwarded to the appropriate Mission Directorate contact. PA&E will enter the CADRe information into the Once NASA Cost Engineering Database (ONCE)

Currently, the CADRe data entry, submission, and interface with ONCE goes through a manual process. This process will change with the automation of the ONCE database. The ONCE database will transform into a web-based system that will allow for online CADRe development as well as allowing for self population of data. This will create a repository of raw data from which analysts may draw information and perform analyses. This database will be populated via an ASP.Net web application and the application will dynamically store the CADRe data as the CADRe is being developed. ONCE will also contain all the source documents (i.e. MS Word, MS PowerPoint, etc.) from which the CADRes were developed. Users should have the ability to upload source documentation to the server and should be able to search, view and download the CADRe information either by project name, phase or by one or more Work Breakdown Structure (WBS) elements, along with searchable technical and cost data from the CADRe.

Value of CADRe Process to NASA

The CADRe consolidates key project data pertaining to technical parameters that drive cost, as well as a project life cycle cost in the project's WBS along with a crosswalk to the NASA's cost estimating WBS. It significantly streamlines the CARD requirement from about a 400 page deliverable to 50 pages. At its core it captures and explains reasons for cost and schedule changes since the last CADRe submission. The benefit of a CADRe is that it provides a basis for an ICE and NASA/IPAO reconciliation and satisfies some key Flight Project Practices gate products. The cost estimates are critical to milestone decisions and determination of project life cycle costs. Furthermore, it provides historical traceability of project changes. Center personnel can use data residing in the CADRe to update cost models with *actuals* to better project future costs of similar systems with greater precision.

Comparison to a CARD

By comparison, a Cost Analysis Requirements Description (CARD) is more labor intensive. A traditional CARD contains 8 sections while a CADRe only has three (e.g., WBS dictionary description, key products and services, description of general cost guidelines, major cost drivers, cost uncertainty, material impact changes, reference information and supplemental information).

While a CARD focuses on capturing a breadth of information, the CADRe focuses on collecting only data required to support decisions. The process is therefore more streamlined and succinct.

To date, developed CARDS are contained on CDs kept at the NASA headquarters Cost Analysis Division. However, with the development of the ONCE database, CADRe data can now be shared among NASA cost estimating and resource stakeholders. Data access will be strictly controlled with only HQ personnel having access to all CADRe data while NASA center personnel will only have access to their own pre-launch CADRe data as well as all CADRes after missions have been launched.

QUESTION: Why Use a CADRe?

ANSWER: Cost estimators use the CADRe's project technical description to develop a project LCCE or ICE. The reconciliation effort of the two estimates measures success and validation, with credibility critical. If the CADRe details or assumptions are wrong, then all estimates will be flawed and reconciliation will be difficult. Cost organizations assist in developing a CADRe but it is owned and signed by the PM.

QUESTION: When is a CADRe Required?

ANSWER: Although no dollar value indicates when a CADRe is required, if an ICE is required, a CADRe is required. Per NPR 7120.5x, NASA requires that an initial ICE be performed prior to entering into Phase B. In general, the threshold for a NASA ICE is over \$250 million for projects moving from Phase A to Phase B. Projects less than \$250 million require an abbreviated NASA CADRe.

4.2 Part II: Cost Methodology Tasks



The next four tasks of the cost estimating process relate to selecting and administering the cost methodology, which will guide the development of the cost estimate. These four tasks are detailed below.

Task 4: Develop Ground Rules and Assumptions (GR&A)

The objective of developing GR&As is to communicate the context/environment within which the estimate is being developed.

There are three activities associated with developing the GR&As:

1. Establish a set of programmatic, technical, and schedule GR&As to define the scope of the estimate (i.e., what costs are being included and what cost are excluded).
2. Achieve consensus on the GR&A with stakeholders, vendors, end users, etc., to ensure their applicability.
3. Fully document the GR&A.

The cost estimator works with the NASA PM and members of the technical team to establish and document a complete set of GR&A that are necessary to provide definition to the project and the estimate and to bound its scope. GR&A let everyone understand what costs are being included and what costs are excluded in the current estimate. This allows for easy comparisons to future estimates and to independent ones. GR&A should be developed in coordination with and agreed upon by the NASA PM. Then, the cost estimator should spend time socializing the GR&A with other stakeholders so that consensus can be built and problems leading inaccurate or misleading estimates can be avoided.

Each estimate should have two sets of GR&A, global and element specific. Global GR&A apply to the entire estimate and include ground rules such as base year dollars, schedules, and total quantities. Detail element GR&A are developed as each WBS element is being estimated and are found in the detail section for each WBS element. Detail element GR&A provide details for each element such as unit quantities and schedules. Since it is impossible to know every technical or programmatic parameter with certainty before and into the design phase of a program/project, a complete set of realistic and well-documented GR&A adds to the soundness of a cost estimate. Descriptions of relevant missions and system characteristics, manning, maintenance, support, and logistics policies are generally included in the GR&A. GR&A are more prominent in less defined Pre Phase A and Phase A projects, because there are more unknowns and are less prominent in well defined Phase B and on projects because there are less unknowns about the program. Global and detail element GR&A can also be found in the CADRe and should be in sync with the estimate.

Following is a list of areas that should be covered by an estimator preparing the GR&A.



- ▶ Guidance on how to interpret the estimate properly.
 - ▶ Clarification to the limit and scope in relation to acquisition milestones.
 - ▶ What base year dollars the cost results are expressed in, e.g., FY04\$.
 - ▶ Inflation indices used.
 - ▶ Percentages (or approach) used for computing program level wraps: i.e., fee reserves, program support, OCD, HQ taxes, Level II Program Office, etc.
 - ▶ Technology assumptions and new technology to be developed.
 - ▶ Production unit quantities, including assumptions regarding spares, long lead items and make or buy decisions.
 - ▶ Quantity of development units, prototype or protoflight units.
 - ▶ LCC considerations: mission lifetimes, hardware replacement assumptions, hardware and software heritage, launch rates, number of flights per year.
 - ▶ Implementation approach aspects such as Integration and test approach/test articles, mission assurance/safety approach, planetary protection approach, launch approval approach, commercialization and outsourcing approach, and partner commitments.
- ▶ Schedule information: development and production start and stop dates, Phase B Authorization to Proceed (ATP), Phase C/D ATP, first flight, Initial Operating Capability (IOC) timeframe for LCC computations, etc.
 - ▶ Use of existing facilities, modifications to existing facilities, and new facility requirements.
 - ▶ Cost sharing or joint funding arrangements with other government agencies, if any (e.g., partnerships), make buy decisions, outsourcing or commercialization approach.
 - ▶ Management concepts, especially if cost credit is taken for charge in management culture, New Ways of Doing Business (NWODB), in-house versus contract, etc.
 - ▶ Operations concept (e.g., launch vehicle used, location of Mission Control Center [MCC], use of Tracking and Data Relay Satellite System [TDRSS], Deep Space Network [DSN], or other communication systems, etc.).
 - ▶ Operations and Support (O&S) period, maintenance concept(s) and if required, training strategy.
 - ▶ Commonality or design inheritance assumptions.
 - ▶ Specific items or costs excluded from the cost estimate.

Task 5: Select Cost Estimating Methodology

The goal of this task is to select the best cost estimating methodology (or combination of methodologies) for the data available to develop the most accurate cost estimate possible.

Within the execution of this task are the following four activities:

1. Determine the type of system being estimated.
2. Determine the life cycle phase of the project.
3. Determine the availability of data.

Exhibit 5-2 illustrates a quick reference chart used for selecting cost estimating methodologies.

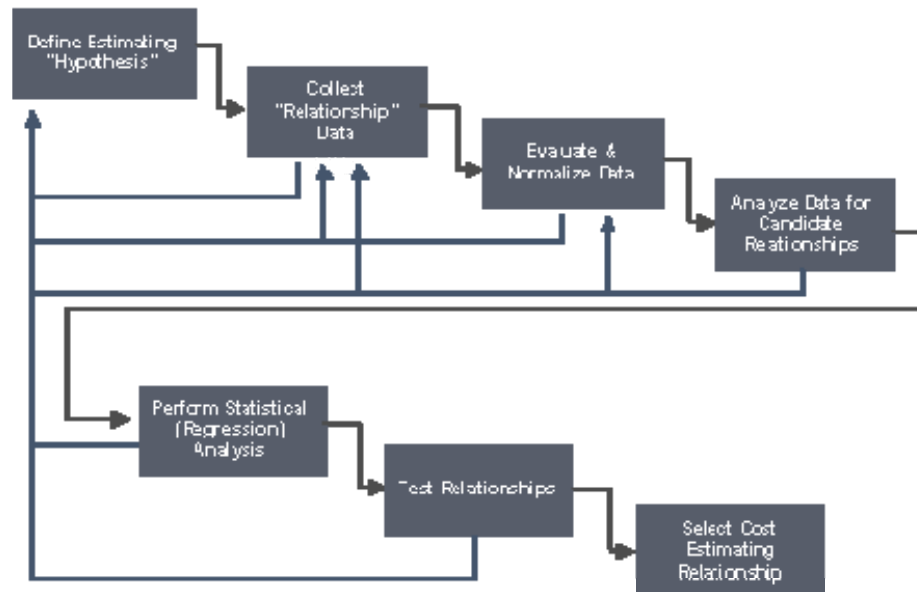
	Pre-Phase A	Phase A	Phase B	Phase C/D	Phase E
Parametric	4	4	2	2	0
Analogy	4	2	2	2	0
Engineering Build Up	2	2	4	4	4

4 Primary 2 Applicable 0 Not Applicable

Exhibit 5-2:
Cost Estimating Methodology Selection Chart

Parametric Cost Estimating

Estimates created using a parametric approach are based on historical data and mathematical expressions relating cost as the dependent variable to selected, independent, cost-driving variables through regression analysis. Generally, an estimator selects parametric cost estimating when only a few key pieces of data are known, such as weight and volume. The implicit assumption of parametric cost estimating is that the same forces that affected cost in the past will affect cost in the future. For example, NASA cost estimates are frequently of space systems or software. The data that relates to estimates of these are weight characteristics and design complexity respectively. The major advantage of using a parametric methodology is that the estimate can usually be conducted quickly and is easily replicated. Exhibit 5-3 shows the steps associated with parametric cost estimating.



**Exhibit 5-3:
Parametric Cost Estimating Process Steps**

In parametric estimating, an estimator either creates his/her own CERs or uses NASA-developed, COTS, or generally accepted equations/models. If the estimator chooses to develop his or her own CERs, there are several techniques to guide the estimator. To perform the regression analysis for a CER, the first step is to determine the relationship between the dependent and independent variables. Then, the data is fit using techniques such as:

- ▶ Linear regression: involves transforming the dependent and independent variables into linear forms
- ▶ Nonlinear regression: for data that is not intrinsically linear

The dependent variable is called that because it responds to changes in the independent variable. For a CER, the dependent variable will always be cost and the independent variable will be the cost driver. The cost driver should always be chosen because there is correlation between it and cost and because there are sound principles for the relationship being investigated. For example, the assumption may be made that the complexity of a piece of computer software drives the cost of a software development project. The dependent variable is the Y variable and the independent the X variable. By plotting historical data on cost to complexity a chart that looks like Exhibit 5-4 may result.

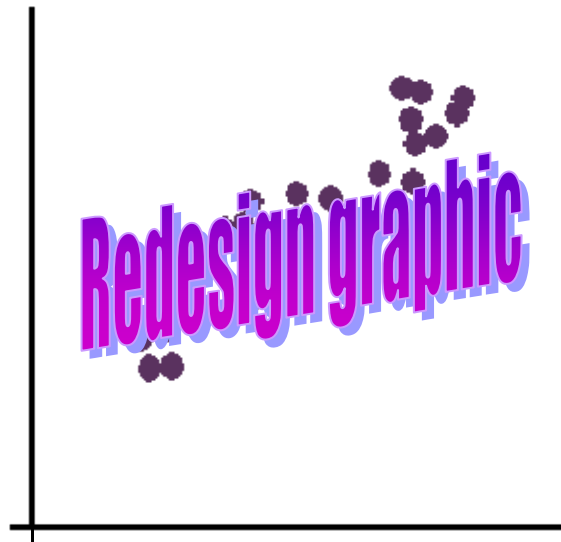


Exhibit 5-4:
Cost Complexity Chart

The point of regression analysis is to “fit” a line to the data which will result in an equation that describes that line, expressed by $y = a + bx$. In this case, we assume a positive correlation, one that indicates that as complexity increases, so does cost. It is very rare that a CER will be developed around a negative correlation, i.e., as the independent variable increases in quantity, cost decreases. Whether the independent variable is complexity or weight or something else, there is typically a positive correlation to cost.

One estimates the parameters of a model. The usual technique is called least squares. A linear regression model is one in which the dependent and independent variables can be transformed into a linear form. A non-linear regression model is one for which there is no such transformation. More formally, a non-linear regression model is one for which the first-order conditions for least-squares estimation of the parameters are non-linear functions of the parameters.

With the addition of possible explanatory variables (see Exhibit 5-5), a more precise and robust regression equation can be obtained. Since more than one independent variable is likely to have an effect on the dependent variable, one can calculate multivariate regression:

Regression Coefficient	Meaning
β_1	Impact of a one-unit increase in X_1 on the dependent variable Y , holding constant all the other included independent variables (X_2 and X_3)
β_2	Impact of a one-unit increase in X_2 on Y , holding X_1 and X_3 constant
β_3	Impact of a one-unit increase in X_3 on Y , holding X_1 and X_2 constant

Exhibit 5-5:
Regression Definitions

The usual method of regression coefficient estimation is using a computer program capable of calculating estimated coefficients with a technique called Ordinary Least Squares (OLS). Exhibit 5-6 provides a reference guide to help evaluate regression results.

Symbol	Check Point	Reference	Decision
X, Y	Data Observations	Check for errors, especially outliers in the data.	Correct any errors. If the quality of the data is poor, may want to avoid regression analysis or use just OLS.
$\hat{\beta}$	Estimated Coefficient	Compare signs and magnitudes to expected values.	If they are unexpected, respecify the model if appropriate or assess other statistics for possible correct procedures.
e_i	Residual	Check for transcription errors.	Take appropriate corrective action.
R^2	Coefficient of Determination	Measures the degree of overall fit of the model to the data.	A guide to overall fit.
\check{R}^2	R^2 adjusted for degrees of freedom	Same as R^2 . Also attempts to show the contribution of an additional explanatory variable.	One indication that an explanatory variable is irrelevant is if the \check{R}^2 falls when it is added.
TSS	Total Sum of Squares	$TSS = \sum (Y_i - \text{avg } Y)^2$	Used to compute R^2 and \check{R}^2 .
RSS	Residual Sum of Squares	$RSS = \sum (Y_i - \hat{Y}_i)^2$	Used to compute \check{R}^2 and \check{R}^2 .

Exhibit 5-6:
Evaluating Regression Analysis Results



QUESTION: What is the Regression Analysis Methodology?

ANSWER: The Regression Analysis Methodology requires the following steps:

- ▶ Review the literature and develop the theoretical model.
- ▶ Specify the model.
- ▶ Select the independent variables(s) and the functional form.
- ▶ Hypothesize the expected signs of the coefficients.
- ▶ Collect the data.
- ▶ Estimate and test the hypotheses regarding the model's parameters.
- ▶ Document the results.

Regression analysis is used not to confirm causality, as many believe, but rather to test the strength and direction of the quantitative relationships involved. In other words, no matter the statistic significance of a regression result, causality cannot be proven. Instead, regression analysis is used to estimate and test hypotheses regarding the model's parameters.

When using the NAFCOM database, the estimator selects the inputs and NAFCOM will calculate the linear regression. Using a COTS package such as SEER (see Appendix P) or PRICE (see Appendix Q) gives the estimator the option to generate the entire estimate or to generate a point estimate to be used as output to another model.

CERs established early must be periodically examined to ensure that they are current throughout the life of an estimate and that the input range of data being estimated is applicable to the system. All CERs should be detailed and documented. If a CER is improperly applied, a serious estimating error could result. Excel[®] or other commercially available modeling tools are most often used for these calculations. Exhibit 5-7 lists some strengths and weaknesses of using parametric methodology to develop a cost estimate.

Strengths	Weaknesses
Once developed, CERs are an excellent tool to answer many "what if" questions rapidly.	Often difficult for others to understand the relationships.
Statistically sound predictors providing information about the estimator's confidence of their predictive ability.	Must fully describe and document selection of raw data, adjustments to data, development of equations, statistical findings and conclusions for validation and acceptance.
Eliminates reliance on opinion through the use of actual observations.	Collecting appropriate data and generating statistically correct CERs is typically difficult, time consuming, and expensive.
Defensibility rests on logical correlation, thorough and disciplined research, defensible data, and scientific method.	Loses predictive ability/credibility outside its relevant data range.

**Exhibit 5-7:
Strengths and Weaknesses of Parametric/CER Cost Methodology**

Analogy Cost Estimating Methodology

Analogy estimates are performed on the basis of comparison and extrapolation to like items or efforts. Cost data from one past program that is technically representative of the program to be estimated serves as the basis of estimate. Cost data is then subjectively adjusted upward or downward, depending upon whether the subject system is felt to be more or less complex than the analogous program. Clearly subjective adjustments compromise completely the validity and defensibility of the estimate and should be avoided. Best-fit, linear extrapolations from the analog are acceptable "adjustments." This estimating approach is typically used when an adequate amount of program and technical definition is available to allow proper selection, and adjustment, of comparable program costs. With this technique, a currently fielded system (comparable system) similar in design and/or operation of the proposed system is identified. An analogous approach is also used when attempting to estimate a generic system with very little definition.

The analogy system approach places heavy emphasis on the opinions of "experts" to modify the comparable system data to approximate the new system and is therefore increasingly untenable as greater adjustments are made. Exhibit 5-8 provides a list of the strengths and weaknesses of using an analogous system method to develop a cost estimate.

Strengths	Weaknesses
Based on actual historical data.	Relies on single data point.
Quick.	Can be difficult to identify appropriate analog.
Readily understood.	Requires "normalization" to ensure accuracy.
Accurate for minor deviations from the analog.	Relies on extrapolation and/or expert judgment for "adjustment factors."

Exhibit 5-8: Strengths and Weaknesses of Analogy Method of Cost Estimating

Complexity or adjustment factors can be applied to an analogy estimate to make allowances including year of technology, inflation, basing modes, and technology maturation. A complexity factor usually is used to modify a CER for complexity (e.g., an adjustment from an air system to a space system). A traditional complexity factor is a linear multiplier that is applied to the subsystem cost produced by a cost model. In its simplest terms, it is a measure of the complexity of the subsystem being costed compared to the composite of the CER database being used or compared to the single point analog data point being used.



Complexity Factors

Tables have been prepared by various NASA cost offices as guidelines to design engineers in making these judgments regarding selection of a complexity factor. Although these are not absolute standards, they may be useful as general guidance if the engineer is having difficulty quantifying his/her assessment of the relative complexities

Source: JSC NASA Cost Estimating Guidelines

QUESTION: How is the value of a complexity factor determined?

ANSWER:

The most uncomplicated approach to determining a value for the complexity factor of a subsystem is to work closely with the design engineer responsible for that subsystem. The following steps would generally be followed to determine the complexity factor. The design engineer (with the assistance of the cost estimator) would:

1. Become familiar with the historical data points that are candidates for selection as the costing analog,
2. Select that data point that is most analogous to the new subsystem being designed,
3. Assess the complexity of the new subsystem compared to that of the selected analog. This assessment would be in terms of design maturity of the new subsystem compared to the design maturity of the analog when it was developed, technology readiness of the new design compared to the technology readiness of the analog when it was developed, and specific design differences that make the new subsystem more or less complex than the analog (examples would be comparisons of pointing accuracy requirements for a guidance system, data rate and storage requirements for a computer, differences in materials for structural items, etc.),
4. Make a quantitative judgment for a value of the complexity factor based on the above considerations, and
5. Document the rationale for the selection of the complexity factor.

Source: JSC NASA Cost Estimating Guidelines

Engineering Build Up Methodology

Sometimes referred to as “grass roots” or “bottom-up” estimating, the engineering build up methodology rolls up individual estimates for each element into the overall estimate. This costing methodology involves the computation of the cost of a WBS element by estimating at the lowest level of detail (often referred to as the “work package” level) wherein the resources to accomplish the work effort are readily distinguishable and discernable. Often the labor requirements are estimated separately from material requirements. Overhead factors for cost elements such as Other Direct Costs (ODCs), General and Administrative (G&A) expenses, materials burden, and fee are generally applied to the labor and materials costs to complete the estimate. A technical person who is very experienced in the activity typically works with the cost analyst, who prepares these engineering build up estimates. The cost estimator’s role is to review the grassroots estimate for reasonableness, completeness, and consistency with the program/project GR&A. It is also the cost estimator’s responsibility to test, understand, and validate the knowledge base used to derive estimates.

Exhibit 5-9 illustrates a method for deriving an engineering build up estimate. While this is a simple illustration of the engineering build up methodology, it is important to remember to conduct other detail activities such as documenting the Basis of Estimates (BOEs) and schedules, and applying wage and overhead rates.

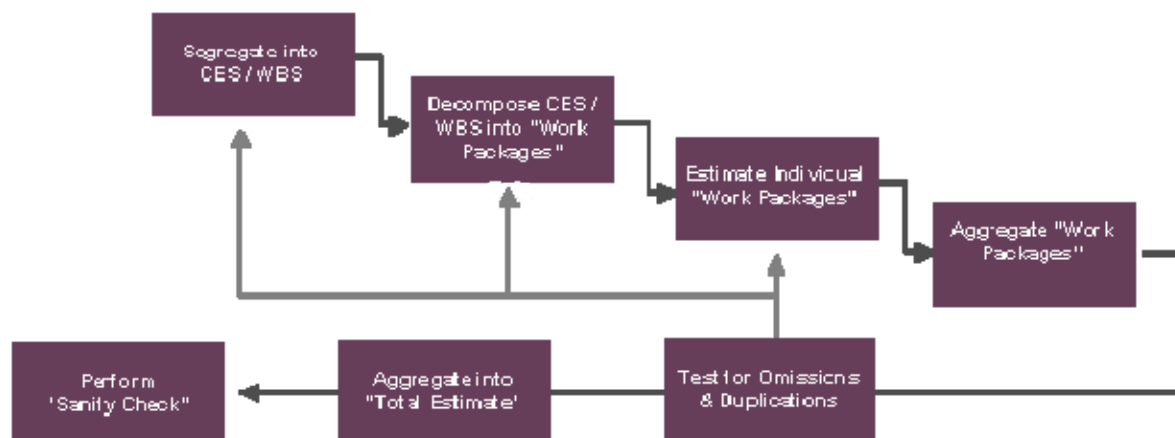


Exhibit 5-9:
Method for Developing an Engineering Build Up Estimate

There are also situations where the engineering community provides their “professional judgment,” but only in the absence of empirical data. Experience and analysis of the environment and available data provides latitude in predicting costs for the estimator with this method. This method of engineering judgment and expert opinion is known as the Delphi method. Interview skills of the cost estimator are important when relying on the Delphi method to capture and properly document the knowledge being shared from an engineer’s expert opinion. Delphi method usually involves getting a group of experts to converge on a value by iterating estimates using varying amounts of feedback. Individuals are generally not identified to the outside, and in some experiments, not identified to each other.

Exhibit 5-10 provides a list of the strengths and weaknesses of using the engineering build up method to develop a cost estimate.

Strengths	Weaknesses
Intuitive.	Costly; significant effort (time and money) required to create a build-up estimate.
Defensible.	Not readily responsive to "what if" requirements.
Credibility provided by visibility into the BOE for each cost element.	New estimates must be "built-up" for each alternative scenario.
Severable; the entire estimate is not compromised by the miscalculation of an individual cost element.	Cannot provide "statistical" confidence level.
Provides excellent insight into major cost contributors.	Does not provide good insight into cost drivers.
Reuse; easily transferable for use and insight into individual project budgets and individual performer schedules.	Relationships/links among cost elements must be "programmed" by the analyst.

**Exhibit 5-10:
Strengths and Weaknesses of Engineering Build Up Method
of Cost Estimating**

Task 6: Select / Construct Cost Model

The objective of this task is to select the most appropriate tool/model or to create a model to estimate the cost. Factors that influence the selection process include data and resource availability, schedule, and cost.

There are three activities associated with selecting or constructing a model.

1. Review available choices and make a selection. If no suitable alternatives exist, explore the option of creating a model.
2. Be prepared to defend the choice.
3. Ensure that the model is full cost compliant.

Modeling is the systematic approach to analyzing a project that is supportive and quantifiable. Many cost estimating models exist, and, similar to the estimating methodologies, no single cost model can be used for all purposes. Some models are a basic construct to be used as a tool while other models are estimating environments that can be all-inclusive and automate many functions for the cost estimator. A model can also use a variety of estimating methodologies and direct inputs to complete a full estimate.

For each methodology described in the previous section, there are a multitude of both commercially available and government developed or owned models from which the cost estimator can make his/her selection. Generally speaking, one of these models and/or tools

should help the cost estimator complete his/her task in a more efficient/effective manner. Many of the tools provide a construct to use for the model, standard WBSs, as well as data and CERs that can be used in the estimate. In addition, many cost estimators use Excel to create their own model when there are estimating needs that cannot be met by commercially available models. Information about many modeling products can be found in Appendices L through U.

Many commercially available models are parametric models that generate estimates based on specific parameters that drive an estimate's cost. These cost drivers include items such as weight, volume, quantity, and schedule. These models can be used when only a few of these input parameters are known to generate a high level estimate. If many of the cost drivers have been identified and there are many known technical input parameters, these models can also be used to generate very detailed and complex cost estimates. Commercially available parametric models use normalized industry data sets in generic and sometimes proprietary algorithms. In many cases these models should be calibrated based on the product that is being estimated to ensure the estimate takes into account factors such as the project environment (e.g., space, air) for a more accurate estimate. If a NASA estimator chooses to create his or her own parametric model with NASA data, the model is in effect, self-calibrated.

In some cases, an estimator may develop an extensive set of CERs for a specific item or to support a specific deliverable or purpose. In such cases, it may be more efficient for the estimator to develop and tailor their own model if the estimator is skilled at CER development, model building, and can have the model validated.

Most commonly used, Excel is a powerful, flexible spreadsheet tool used by the Government and the private sector. Due to its popularity, a lot of employees in the industry are savvy users and can deliver impressive models using the formulas, graphs, and Visual Basic functions that are embedded in the software. The Microsoft software package, including Access, Excel, PowerPoint, and Word are compatible with each other, which creates a seamless environment of automated tools. The advantage of creating your model in Excel is the ability of having a "glass box" model where all formulas and intricacies of your creation can be traced easily. The powerful formula and Visual Basic functions that are part of Excel provide endless avenues of creative model formulation. The ability to transfer the model from one place to another is fluid.

The disadvantage of creating a model in Excel is that the cost estimator needs to build the model from scratch. The analyst must take the time to draw the layout of how the model is going to look and how all the equations are going to fit together. Excel does not have embedded risk tools in the software but add-in tools are available to conduct risk analysis. Some of these add-in risk tools are listed in Appendix M.

If an estimator chooses to build his or her own model, following a disciplined process will ensure a credible product. Once the estimator has identified the need for a model and determined the model type, the model design can begin. The importance of spending time up front to design and understand the model cannot be underestimated. The model developer needs to define the scope of the model, how it will ultimately be used, and the approach for integrating the data and CERs collected and developed. While planning the development, it is important to document the model GR&A that will be used. The modeling environment is the next decision that should be made. The environment chosen may affect the complexity of the model and the resources required for the software development, testing, and validation.

After the model has been developed and populated with at least preliminary cost data, it must be validated before the estimator uses it. Once the model has been validated and any corrections or

updates incorporated, it is fit for use to generate estimates. To complete the model development process, user documentation and training should be prepared.

Task 7: Gather and Normalize Data

The objective of this task is to arm the cost estimator with as much information as possible so that he/she can develop the most accurate and justifiable cost estimate.


There are four activities associated with gathering and normalizing data.

1. Identify data needed and potential data sources.
2. Review, interview, and/or survey data sources to obtain data.
3. Conduct project schedule analysis.
4. Normalize data.

Data collection is one of the most difficult, time-consuming, and costly activities in cost estimating. Data needs are not always clear at the assignment's beginning and data requirements often evolve during an estimate's development. An estimator needs to recognize that data adjustments may be necessary to support a particular NASA Project Office's need.

It is also critical to collect risk data at this time to support the cost-risk assessment. Many of the experts that will be interviewed and the data that will be reviewed in this effort will not only support the cost estimate, but can assist in identifying risks early, and can also save time by reducing data collection later in the process during the cost risk assessment.

Typically, this is the step in the process where data collection occurs. However, as previously noted, data collection can occur in earlier steps, such as collecting data for regression analysis to support a methodology or even earlier in the process when the estimator is understanding the project. The following are potential mechanisms available to the cost estimator for identifying quantitative cost data:

- 
- ▶ Surveys and/or questionnaires,
 - ▶ Model specific data collection/input forms,
 - ▶ Interviews,
 - ▶ Focus groups,
 - ▶ Target research (public domain or otherwise), including reviews, papers, and statistical analysis, and
 - ▶ Specific cost, technical, and programmatic data from primary and secondary sources.

QUESTION: When is a Non-Disclosure Agreement (NDA) required for non-government employees?

ANSWER: Non-disclosure agreements (NDAs) are required for non-government employee access to Confidential Business Information (CBI), which includes proprietary and competition-sensitive contractor data. Applicable NDAs

must be in-place between the originating and requesting organizations before access to such information can be approved.

NASA places the highest priority on protection of contractor technical and cost data. Federal employees are subject to the relevant provisions of the Federal Trade Secrets Act. For further information on this subject, contact Ron Larson at HQ Cost Analysis Division (202.358-0243 or e-mail <Ronald.Larson-1@nasa.gov>) for further information on this subject.

Based upon the resources, the schedule and the expectations, the estimator should use as many of these data collection methods as can be supported. Exhibit 5-11 provides a list of data types and sources. The cost estimator will work with the PM and members of the technical team to obtain the technical and programmatic data required to complete the cost estimate. Typically, these requirements are contained in a document, or set of documents such as a technical baseline or CADRe. A well-documented set of project requirements ensures that the cost estimators are estimating the same product that is being designed by the technical team. If some of the cost model inputs are not explicitly contained in the requirements document, the cost estimator will have to coordinate with the cognizant technical point of contacts to obtain the needed data by interview techniques and/or by survey mechanisms. Schedule analysis is another important part of data collection. More information on this technique can be found in Section 6.17.

Once data has been collected it needs to be normalized. Normalization involves analyzing the raw data collected and adjusting it to make it consistent. The inconsistencies that may be found in a data set include changes in dollar values over time (inflation), learning or cost improvements for organizational efficiency, and if more than one unit is being produced, the effects of production rates on the data set being analyzed.

When analyzing a data set, normalization considerations should include adjustments for cost (currency, base year), size and weight, complexity or mission, recurring/non-recurring and the mission platform (crewed, robotic).

		Three Principal Types of Data	
		Data Type	Data Sources
Data Category	Cost Data	<ul style="list-style-type: none">▶ Historical Costs▶ Labor Costs▶ CERs from previous projects	<ul style="list-style-type: none">▶ Basic Accounting Records▶ Cost Reports▶ Historical Databases▶ Contracts (Secondary)▶ Cost Proposals (Secondary)

	Technical / Operational Data	<ul style="list-style-type: none"> ▶ Physical Characteristics ▶ Performance Characteristics ▶ Performance Metrics ▶ Technology Descriptors ▶ Major Design Changes ▶ Operational Environment 	<ul style="list-style-type: none"> ▶ Functional Specialist ▶ Technical Databases ▶ Engineering Specifications ▶ Engineering Drawings ▶ Performance / Functional Specifications ▶ End User and Operators
	Project Data	<ul style="list-style-type: none"> ▶ Development and Production Schedules ▶ Quantities Produced ▶ Production Rates ▶ Equivalent Units ▶ Breaks in Production ▶ Significant Design Changes ▶ Anomalies (e.g., strikes, natural disasters, etc.) 	<ul style="list-style-type: none"> ▶ Project Database ▶ Functional Organizations ▶ Project Management Plan ▶ Major Subcontractors

**Exhibit 5-11:
Data Types and Sources**

Normalizing data for cost includes adjusting for inflation. This inflation adjustment is only to make the raw data set consistent and fit for use in CERs, models, or estimates. This data may be adjusted for inflation again in Task 8 when it has been incorporated into the cost estimate and the estimate as a whole is adjusted for inflation. The full estimate may be adjusted for inflation to show the results in BY, CY or TY dollars. Exhibit 5-12 defines some common terms used for inflation and escalation.

Term	Definition
Base Year (BY) Dollar	A point of reference year whose prices form the basis for adjusting costs or prices from other years.
Constant Year (CY) Dollar (ConstY)	Money or prices expressed in terms of values actually observed in the economy at any given time. Constant dollars represent the purchasing power of dollars tied to a particular base year's prices; the base year must be identified, e.g. constant FY04 dollars.
Current Year (CY) Dollar (CurrY)	Money or prices expressed in terms of values actually observed in the economy at any given time. Current dollars represent the purchasing power of dollars at the time they are expended. (This is what NASA Calls Real-Year dollars, though that term is counter to its usage in DoD and other Federal departments, where real dollars means constant dollars.
Budget Dollar	Total Obligation Authority (TOA) inflated according to the amount of escalation used in the current budget year.
Then Year (TY)	TOA that includes a slice of inflation to cover escalation of

Dollar	expenditures over a multiyear period.
Real Year (RY)	Money expressed as spent dollars.
Inflation Rate	The % change in the price of an identical item from one period to another.
Outlay Profile	In percentage terms, the rate at which dollars in each appropriation are expected to be expended based on historical experience.
Raw Inflation Index	A number that represents the change in prices relative to a base period of 1.0000. Typically periods are 1 year.
Weighted Inflation Rate	Combines raw inflation indices and outlay profile factors to show the amount of inflation occurring over the entire period needed to expend the TOA.
Composite Inflation Index	A weighted average of the inflation indices for the applicable sub-appropriations.

Exhibit 5-12: Inflation and Escalation Terms

The Cost Analysis Division in the Office of the CFO at NASA HQ provides an annual update of the NASA New Start inflation index (<https://secureworkgroups.grc.nasa.gov/casg?go=205946>) to be used to prepare cost estimates for new R&D projects. These inflation indices can be used for:

- ▶ Inflating cost model results expressed in terms of ConstY costs to real year dollars for budgetary or POP purposes (use for inflating estimates in Task 8),
- ▶ Converting from constant dollars expressed in one year to constant dollars expressed in a different year, and
- ▶ Normalizing historical cost data expressed in real year (as-spent) dollars to ConstY dollars (use for inflating or deflating raw data in Task 7).

Through escalation, inflation adjusts costs to reflect the decrease in the purchasing power of money over time. The inflation factor is the "multiplier" used to account for the change in price of a product or service over time. Escalation factor (or weighted inflation) is the "multiplier" used to account for inflation plus the normal occurrence of allocating money in one year and it being spent over a number of years. An inflation calculation example is provided on the next page.

While inflation is the most common data normalization technique to improve consistency in a data set, there are other normalization techniques that can be just as important. Adjustments for learning or cost improvement curves may apply to the data set that you have collected. Production rate (units produced over a time period) may also have an effect on the raw data set, which calls for adjustment. In the case of production rates there may be patterns or influences in the production of the item such as facilities or manpower that affect the data. At NASA there are not many projects that involve production, however data collected from other sources that may be used in NASA estimates may have production considerations that should be taken into account. Other adjustments that may need to be made to normalize data include:

- ▶ Checking for scope consistency between product for the historical data and the product being estimated,
- ▶ Unusual events or anomalies in a projects life, such as extra testing, failures or labor anomalies,
- ▶ Technology improvements and advancements, where the data may need to be adjusted by using engineering judgment,
- ▶ Raw data adjustments from reporting system anomalies or changes, such as a change in rates, factors or hours for standard reporting,
- ▶ Reporting system differences which may require mapping accounting classifications to WBS elements, and
- ▶ Reporting system differences for categories of data with different definitions for the same item from one system to another.



Inputs (FY2002\$)					
		FY02	FY03	FY04	Total
Example 1	BY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Example 2	CY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Example 3	TY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
BY Inflation Factor (a)		100.000	100.000	100.000	
Weighted Inflation Factor (b)		100.000	103.100	106.300	
Multiplier (a)/(b)		1.000	0.970	0.941	
Outputs (FY2002\$)					
Example 1	BY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Total		\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Example 2	CY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Inflation Factor		1.000	0.970	0.941	
Total		\$ 100.000	\$ 96.993	\$ 94.073	\$ 291.067
Example 3	TY	\$ 100.000	\$ 100.000	\$ 100.000	\$ 300.000
Inflation Factor		1.000	0.970	0.941	
Total		\$ 100.000	\$ 96.993	\$ 94.073	\$ 291.067

Inflation Table

Code:	108	
Term:	R&D	
Database:	System	
Source:	HQ NASA	
RevDate:	16-Apr-99	
<u>Year</u>	<u>RAW</u>	<u>WTD</u>
2000	94.100	94.100
2001	97.000	97.000
2002	100.000	100.000
2003	103.100	103.100

2004	106.300	106.300
2005	109.500	109.500
2006	112.900	112.900

Once data has been normalized it should be reviewed and validated. When reviewing data the estimator should ensure that a consistent data collection methodology, consistent data collection formats, and procedures to identify data anomalies are in place. Considerations such as data sufficiency to support the estimating methodology selected and documentation to ensure traceability of adjustments made to the data are also critical. These documented factors assist the estimator with the validation of the data and lead to data reliability and ultimate estimate credibility.

If an estimator takes each of these steps into consideration when identifying and collecting data, analyzing schedules, and normalizing data, the repeatability and credibility of the data supporting the estimate will be improved.

4.3 Part III: Estimate Tasks

The last five tasks of the cost estimating process revolve around the actual generation and documentation of the estimate. These tasks are detailed below.



Task 8: Develop Point Estimate

The goal of this task is to create an accurate LCC point estimate to be used in conjunction with the cost risk assessment to develop the final estimate.

There are eight activities associated with developing a point estimate.

1. Populate model with the normalized data collected.
2. Verify the GR&As.
3. Ensure the estimate is full cost compliant.
4. Run the model to calculate cost.
5. Time phase the estimate.
6. Adjust the estimate for inflation
7. Conduct any cross check estimate or estimate reconciliation.
8. Develop or update cost track to previous or independent estimate.

Once the model has been selected or constructed and the data has been gathered, the next step is to populate the model. Once the model has been populated with the data, according to the GR&A, the model is run and a point estimate established. Next, the data are properly time phased according to the planned deployment or integration schedule. This can be done using many techniques, including beta curves (see Appendix W), historical spreads, engineering judgment, or budget constraints. Just as the data needed to be normalized for inflation, the estimate must also be adjusted for inflation over its life cycle.

Before and after running the model it is important to check and recheck formulas and data entry to ensure accuracy and to document each input and formula for the detail estimate documentation. Another important step to remember is to conduct a cross check estimate, using an alternative methodology on your point estimate. This is important to ensure a “sanity check” on the original estimate and to show an alternative estimate view of the data. In addition,

keeping the estimate up-to-date helps to defend the estimate, reduce updated estimate turn-around time, and gives the decision-maker a clearer picture for “what if” drills or major decisions.

Task 9: Develop Reserves from Cost Ranges / Cost Risk Assessment

The objective of this task is to produce a credible project cost “S”-curve - that is, the CDF for the range of costs of the project.

There are six activities associated with developing reserves from cost ranges and conducting the cost risk assessment.

1. Determine the project’s cost drivers with input from the PM and staff.
2. Develop probability distributions for the cost model uncertainty.
3. Develop probability distributions for the technical and schedule cost drivers.
4. Run Risk Model.
5. Identify the probability that the actual cost is less than or equal to the point estimate.
6. Recommend sufficient reserves to achieve the 70% confidence level.

Cost risk assessment is the process of identifying and analyzing critical project risks within a defined set of cost, schedule, and technical objectives and constraints. It is balancing the probability of failing to achieve a particular outcome against the consequences of failing to achieve that outcome. This task also allows the cost estimator to document risks in a manner that accommodates proactive management of project costs. Details about how to conduct cost risk assessments are provided in Section 6.16, the 12 Tenets of Cost-Risk.

The cost risk assessment process forces the consideration of cost risks by the cost estimator and the PM and provides tangible data for use as the basis of decisions. The process enhances underestimating complexity of system development, attaches valuation to risk reduction activities/risk mitigation plans and integrates cost analysis and the formal technical assessment conducted by the Project known as Probabilistic Risk Analysis (PRA).

Cost risk must be carefully and quantitatively assessed in developing and presenting any cost estimate for several reasons. First, when trade studies are conducted, a single cost estimate, such as an expected cost, may mislead the trade team by not revealing the potential for overruns. Second, at Confirmation Reviews and Authority to Proceed decision points, the cost estimate must include an appropriately chosen level of reserves. The objective of a cost risk analysis is to produce a credible project cost S-curve—that is, the cumulative distribution function for the cost of the project without reserves.

To quantify the cost impacts due to risk, one must first identify the sources of risk. There are three sources of risk for which cost-risk analysts should be concerned.

- The first is the risk inherent in the cost estimating methodology. For example, if a regression-based CER is used, it has an associated standard error of the estimate (SEE), confidence intervals, and prediction intervals, any of which can be used to include cost estimating methodology risk in the estimate. Cost risks are those risks due to economic factors such as rate uncertainties, cost estimating errors, and statistical uncertainty inherent in the estimate. Cost risk is dependent upon other fundamental risk dimensions (technical and schedule risks) so these must all be assessed to arrive at a true picture of project risk.

- ▶ The second source of risk is the risk inherent in the technical aspects of the systems being developed. Into this category of risk fall risk sources such as the technology's state of the art (TRLs are good indicators of this risk source), design/engineering, integration, manufacturing, schedule, complexity, etc. Quantifying the cost impacts due to these kinds of risk is not as statistically derivative as was CER risk. For this source of risk, a commonly used technique involves constructing a two-dimensional matrix where the rows are risk source drivers such as state of the art, design/engineering, integration, etc., and the columns are intensities such as low risk, medium risk, high risk. A technique known as Relative Risk Weighting adds a dimension for describing a worst case, best case, and reference case with respect to "technical" risk. This three-dimensional matrix produces relative scores for each case and cost-risk adjustment factors for constructing triangular WBS cost-risk distributions.
- ▶ The third source of risk for cost impacts is the correlation between WBS elements. Correlation assessment determines to what degree one WBS element's change in cost is related to another's and in which direction. For example, if the cost of the satellite's payload goes up and the cost of the propulsion system goes up then there is a positive correlation between both subsystems' costs. Many WBS elements within space systems have positive correlations with each other and the cumulative effect of this positive correlation tends to increase the range of the possible costs.

The cost risk assessment produces a credible project cost "S"-curve – that is, the cumulative distribution function for the range of costs of the project. NPR 7120.5x specifies the use of probabilistic cost risk analysis to quantify uncertainties in cost estimates. Quantifying these risks allows the estimator to address uncertainties in technical design, especially in Pre Phase A, Phase A and Phase B. It is also important for the estimator to address uncertainties in cost estimating methods (e.g. statistical variance in CERs) and provide decision makers range of cost outcomes as a function of confidence levels, and use these results for reserve determinations and recommendations. As the project proceeds through the lifecycle phases, the variance in the estimate narrows.

Cost risk must be carefully and quantitatively assessed in developing and presenting any cost estimate. As shown in Exhibit 5-13 the cost S-curve provides more information than a single number and can be used to choose a defensible level of reserves. The methods for developing a project's cost S-curve depend on the cost estimating methodology employed and the amount of risk information that the cost analyst can secure within the bounds of time and resources.

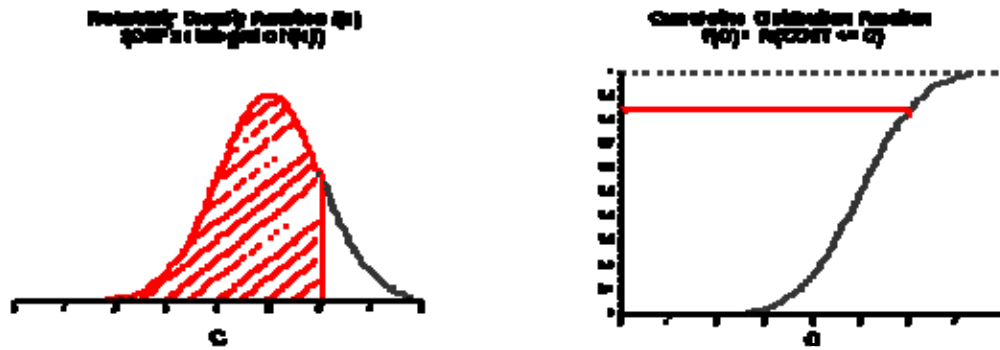


Exhibit 5-13:
A Probability Density Function (Left) and
Its Cumulative Distribution Function or S-Curve (Right)

The derivation of risk reserves for planning purposes begins with the probabilistic cost estimate range. As possible cost impacts due to estimation, technical, programmatic, and dependency risks are incorporated into the cost estimate, the reserve at the LCC level is identified. This reserve is quantified as the difference between the arithmetic sum of the WBS reference point estimates and the cost at the 70th percentile level of confidence. The 70th percentile level is chosen due to the NASA corporate risk reserve requirement for a not-to exceed 80th percentile Mission Directorate-level risk reserve. If each project within a Mission Directorate is budgeted at the 80th percentile level the Mission Directorate risk reserve will be statistically equivalent to approximately 96th percentile level, which is unacceptable from a Congressional appropriation request perspective.

In addition to determining the S-curve, conducting cost risk assessments contribute to:

- ▶ Determining the project's cost drivers. Analyzing which input variables will have a significant effect on the final cost can help determine which design (or programmatic) parameters deserve the most attention during the project's definition and design phase.
- ▶ Estimating the probability of achieving the point estimate. When a simulation risk analysis technique is performed using the low, most likely, and high values provided for the input variables, it can often be demonstrated that the point estimate has a less than 50-50 chance of being achieved.
- ▶ Providing a cost range. A cost range is often more useful to a PM than a point estimate as it provides a series of low and high values of the input parameters to establish the low end and the high end of the cost estimate.

Once the LCC model is fully developed with the input variable distributions, the model can then be subjected to a Monte Carlo simulation. A Monte Carlo simulation calculates numerous scenarios of a model by repeatedly picking random values from the input variable distributions for each "uncertain" variable and calculating the results. Typically, a simulation will consist of 2,500 to 10,000 iterations. The results of Monte Carlo simulations are risk-adjusted estimates and corresponding statistical estimate distributions. The estimate distributions provide the decision-maker with a range of possible outcomes and bounds, with a minimum and maximum value.

(The input variable distributions and cost estimate range is provided with each alternative analysis.)

QUESTION: Why is it important to conduct a cost risk analysis?

ANSWER: Cost risk analysis quantifies the budget reserves necessary for acceptable level of confidence. When asked how much of the dollar figure being proposed is for management reserve, a good strategy is to prepare the calculation below in advance, so that you can respond to that question by saying that the percentage (namely, whatever $[(80\text{th}-50\text{th})/50\text{th}]\times 100\%$ turns out to be) is the amount by which the 80th percentile cost exceeds the 50th, and therefore can be considered "management reserve." Generally HQ Cost Analysis Division will recommend budgeting at 70% to 85%, (70% standard) confidence levels, depending upon project scope, importance, and sense of completeness of the risk analysis. Risk dollars should be phased in the estimate where they will most likely be needed. Most often the risk dollars are needed when common problems manifest between PDR and CDR and then again during Integration and Test. High leverage risk mitigation is commonly most effective prior to PDR.

It is recommended that a sensitivity analysis be performed to identify the major cost drivers, i.e., those variables whose changes create the greatest changes in cost. Sensitivity analysis helps to determine how the different ranges of estimates affect the point estimates. For decision-makers a range estimate with an understanding of the certainty of how likely it is to occur within that range is generally more useful than a point estimate. Due to the nature of the NASA design and development process there will always be uncertainty about the values of some, if not all, of the technical parameters during the definition phase of a project. Likewise, many of the assumptions made at the beginning of a project's definition phase will turn out to be inaccurate. Therefore, once the point estimate is developed, it is often desirable to determine how sensitive the total cost estimate is to changes in the input data.

While sensitivity analyses can occur at any stage of an estimate, it generally makes sense to derive an unconstrained solution that meets all mission objectives initially, then begin to "back off" that solution in the interests of saving money. Care must be taken, however, not to impact the material solution to such an extent that the benefits derived from that solution are significantly altered through introduction of the changes.

Cost Risk Analysis For Parametric Estimation

Any CER estimated value has some uncertainty associated with the statistical properties of the CER; these are *not* indicators of the inherent project risks. It is likely that at the time a parametric estimate is made for a project, some analytical work has been done in the form of a conceptual study or a *Design Reference Mission*, but the detailed technical and schedule/programmatic risks have yet to be understood. As a proxy for these risks, it is common to place probability distributions on the continuous inputs (such as mass) in the estimating relationship, and to use Monte Carlo simulation to develop the project cost S-curve.

Such probability distributions are often subjective. The usual source for the needed probability distributions is the responsible engineering team, though the analyst should be aware of the potential for advocacy optimism here as well. In any case, any probability elicitation and encoding should follow established protocols and methods such as those described in Morgan and Henrion.

Cost Risk Analysis For Analogy Estimation

Even with analogy estimation, it is possible to capture cost risk and build a project cost S-curve. As with a parametric estimation, analogy estimation often is made for a project before the detailed technical and schedule/programmatic risks have yet to be understood. In analogy estimation, each estimator, usually a discipline expert with substantial project experience, scales an analogous project's actual cost, taking into account changes in requirements, technology, and other project implementation decisions. As a proxy for project risks, each scaling factor can be represented by a subjective probability distribution, thus turning a point estimate into probability distribution. Monte Carlo simulation is then used to develop the project cost S-curve. As with any subjective probability elicitation, established protocols and methods should be used.

Cost Risk Analysis For Engineering Build Up Estimation

A cost risk analysis for grass-roots estimation requires an understanding of the sources of cost risk. A thorough risk analysis of the project should have already identified those elements of the WBS that have significant technical and schedule/programmatic risk. Typically these risks arise from inadequacies in the project definition/requirements information, optimistic hardware and software heritage assumptions, the requirement for large advances in the state of technology, and overestimating the performance of potential contractors and other implementers. Two methods (described below) are available for performing a cost risk analysis when performing a grass-roots estimate. The cost risk analysis method used should be identified along with the analysis data.

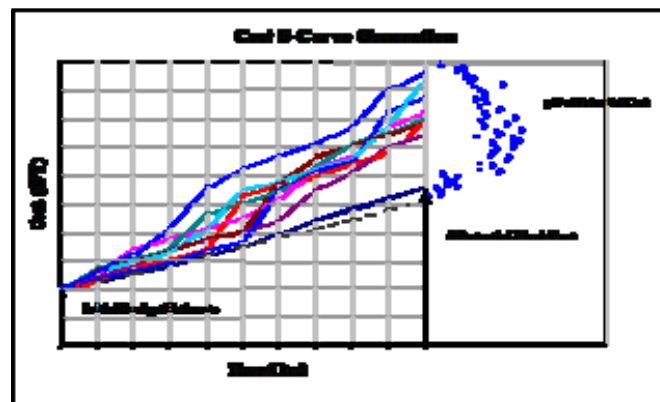
Method 1

For each WBS element identified as a significant risk, a three-point cost distribution (typically, the minimum, maximum, and most likely) is elicited from the individual(s) responsible. Monte Carlo simulation software (available either from in-house or commercial sources) combines these individual (triangular) distributions into a project cost S-curve. The beta distribution may be a better choice to use in the Monte Carlo simulation, but elicitation of its parameters can be more problematical. Research, however, has indicated that certain simple three-point approximations work very well in this context, allowing for improvements in the quality of the S-curve without additional effort.

Method 2

For each WBS element identified as a significant risk, “worst case” (actually, 99th percentile) costs are elicited instead. These elicited values are conditional on the proposed budget (without reserves), performance attributes, and schedules specified in the grass-roots estimates. To obtain the conditional cost S-curve, the Monte Carlo simulation tool combines them. Method 2 is based on different behavioral assumptions and uses a different mathematical approach (a constrained Weiner process) than Method 1. A spreadsheet tool is available to perform the Monte Carlo simulation and produce both a cost density function and cost S-curve. (See example below.) Schedule risk information, if it is available, may be added to the analysis to improve the quality of the S-curve.

Results of Method 2 Applied to a WBS Element



Choosing the Level of Reserves

The level of reserves or reserve percentage should be selected based on achieving a particular *level of confidence* from the resultant cost S-curve for the entire program/project. The appropriate level of confidence is chosen by the Program/Project Manager after the analysis, and the resulting reserves should be identified as the recommended level at all Confirmation Reviews.

For trade studies and formal analyses of alternatives, the cost analyst may choose to add reserves so as to hold the level of confidence constant across all alternatives and report the resulting cost, or to add reserves so as to hold the cost constant and report the resulting level of confidence.

The level of reserves or reserve percentage should be selected based on achieving a particular *level of confidence* from the resultant cost S-curve for the entire program/project. The appropriate level of confidence is chosen by the Project Manager after the analysis, and the resulting reserves should be identified as the recommended level at all Confirmation Reviews.

For trade studies and formal analyses of alternatives, the cost analyst may choose to add reserves so as to hold the level of confidence constant across all alternatives and report the resulting cost, or to add reserves so as to hold the cost constant and report the resulting level of confidence.

Cost Growth

How is it Calculated?

A Weiner process (a type of Markov process) simulates cost growth over T periods using the simple stochastic equation shown here. Each WBS element has a characteristic volatility parameter, s , which is derived from the 99th percentile elicitation and the element's duration. Since the cost growth process is stochastic, many runs are performed for each WBS element to generate a cost probability density function (PDF) like the one shown in the example below. This can be done simultaneously for all WBS elements identified as a "significant risk", and correlations across WBS elements can be represented. The cost S-curve is generated by Monte Carlo methods by combining all the cost density functions.

The Cost Growth (Weiner) Equation

$$dC(t) = a C(t) dt + s C(t) dw$$

with an added constraint that $dC(t) \geq a C(t) dt$ for $t \in [0, T]$.

The choice of the units for t is application dependent.

Assuming t is measured in years, then

$C(t)$ = predicted cost at time t in year t dollars

$C(0)$ = initial WBS element budget estimate in base year dollars

a = inflation rate (%/year)

s = volatility parameter (%/year^{1/2})

T = WBS element duration (years)

dw = a random variable distributed $N(0, dt)$, i.e. dw is normally distributed with mean zero and variance dt .

Ebbeler, Donald H., George Fox and Hamid Habib-agahi, "Dynamic Cost Risk Estimation and Budget Misspecification", AIAA-2003-xxxx, September 2003.

Morgan, M. Granger, and Max Henrion, *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, New York: Cambridge University Press, 1990.

Zaino, N.A., and J.D. D'Errico, "Optimal Discrete Approximations for Continuous Outcomes with Application in Decision and Risk Analysis", *J. Op. Res. Soc.*, 40(1989), pp. 379-388.

Task 10: Document the Cost Estimate

The objective of this task is to capture, in a continuous fashion, from project initiation through completion, the LCC results of the cost estimating process, and all of its by products (confidence levels, CRL, risk reserves).

There are three activities associated with documenting the cost estimate:

1. Document the LCC.
2. Determine the quality of the cost estimate, fitness for use, and document the CRL (see Section 6.1).
3. Conduct peer review.

The purpose of the cost documentation is to provide a written justification for the program cost estimate. Given the size and importance of programs, the documentation clearly should be viewed as a substantive and professional effort. A general rule-of-thumb is that the final product should provide sufficient information on how the estimate was developed so that independent cost analysts--or other review team members--could reproduce the estimate. Although standardization of the content and format of the cost estimate documentation across all NASA Centers is unrealistic, it is recommended that each Center maintain as much consistency internally with respect to the documentation content and format as possible since this promotes completeness and quality agency-wide of the cost estimate's documentation. Cost estimators document the LCC results throughout the entire cost estimating process—not just when the estimate is complete. The final documentation should capture both the estimates for each element supporting the point estimate and the cost risk assessment integration.

The means by which each part of an estimate has been derived must be fully explained, and the databases employed must be provided in the documentation or clearly identified. A Comparison Cost Track by element to identify and explain any deviations between the estimate and the prior estimate should also be included. If other alternatives are being considered, a brief summary of each alternative should also be included.

Cost documentation provides:

- ▶ A written justification for the project cost estimate.
- ▶ A brief description of the system with a brief technical and operational concept description.
- ▶ Methodology and/or models used.
- ▶ Sufficient information on how the estimate was developed to allow independent cost analysts or other review team members to reproduce the estimate if required:

- Inflation and other supporting assumptions
 - Data used to calibrate any CERs.
 - New facilities, initial spares, and other start-up investment costs
 - Operations costs with specific operational scenarios
 - Sunk costs and project remaining life-cycle costs by phase.
 - Net Present Value
- ▶ The means by which each part of an estimate and the databases used can be fully explained.
 - ▶ Schedules (e.g., Systems Engineering Master Schedule).
 - ▶ Acquisition strategy.
 - ▶ Cost S-curve and reserves sufficiency analysis.
 - ▶ Sensitivity analyses.
 - ▶ A comparison track to identify and explain any deviations between the current estimate and any prior estimate.
 - ▶ Cost Readiness Level (CRL).

The benefit of a well-documented estimate is that the differences with other cost estimating efforts for the same program/project should be easily reconcilable from the documented information. Its value is in providing an understanding of the cost elements so that decision-makers can make informed decisions.

Reasons why proper documentation is important in a cost estimate include:

- ▶ Experience from formal cost reviews, such as NARs, has proven that poorly documented analyses do not fare well. The credibility of the total project suffers if the analyst is unable to explain the rationale used to derive each of the cost estimates. Conversely, if a reviewer understands your inputs, approach, and assumptions, your estimate remains credible in his/her eyes regardless of whether disagreements remain or adjustments are recommended.
- ▶ If the BOE is explicitly documented, it is easier to modify key assumptions as they change during the course of the project life cycle, facilitating updates to the estimate and providing a verifiable trace to a new cost baseline. Importantly, this supports the requirement imposed by NPR 7120.4 to revalidate the Program Cost Commitment (PCC) annually. A well-documented CADRe not only facilitates the establishment of the baseline PCC, but also aids the revalidation process and the development of updated PCCs.

Documentation should include a qualitative assessment of each line item, along with risk confidence levels for each element. The summary is where the detailed estimate is located. The level of detail varies with the estimate but the rule of thumb is enough detail to be replicable by another estimator. Supporting data too complex for this section should be included in the appendix. It is important for the documentation to be accessible which means not just available in the actual cost model. There should be an accompanying written document such as a BOE that provides an explanation of estimate details and data sources.

A peer review is another important part of completing an estimate. Once the estimate has been completed and documented and before the estimate is presented to decision makers it is important for the estimator to get an outside review. This “sanity check” can provide an outside perspective and a fresh view of the estimate, which can catch any issues with the estimate to be corrected before presentation. This review can also prepare the estimator for the actual process of

briefing the estimate to decision makers. A peer review can be conducted continuously during the cost estimating process or at any point along the way, but should be completed in full once the estimate is complete and documented.

Cost Documentation

- ▶ Begin documentation efforts early and continue throughout the full estimate development process. Document sources in the actual models and carry these documentation details through to the estimate write up as well as the estimate presentations.
- ▶ When a CER is used, it should be presented and its source must be cited fully, or the model and the set of data with which it was calibrated must be cited. A cost estimator reviewing the cost documentation should be able to obtain enough information either from the document or from the sources cited therein to reconstruct the CER and evaluate its associated statistics. CER documentation should include descriptive statistics, such as R-squared, correlation coefficients, T-statistics, relevant range, etc. This information is necessary to assess the applicability of a CER adequately.
- ▶ Where subjective judgments (Delphi methodology) are used to adjust estimates made by analogy with other systems or components of systems, the professions of those making the judgments must be identified (e.g., cost analysts, engineers, etc.,) and full citations for the source(s) of the costs of each element in an engineering or “grass roots” estimate must also be cited.
- ▶ Present detailed examples of the first and second levels of the cost elements normally included in LCCEs for the each phase.
- ▶ When used in the estimate, actual cost history from past or present contracts or analogous programs should be provided.
- ▶ Areas of uncertainty such as pending negotiations, concurrency, schedule risk, performance requirements that are not yet firm, appropriateness of analogies, level of knowledge about support concepts, critical assumptions, etc., should be presented.
- ▶ Sensitivity analysis should be performed to include the cost of changing significant input parameters. Risk analysis should include risk adjusted point estimates. Crosschecks should be included for all high cost/high risk portions of the estimate.
- ▶ Tracking through a comparison or cost track is required when an estimate changes. Documentation must include the specific reasons for the change.

QUESTION: What items need to be included in a Detailed Cost Estimate Summary?

ANSWER: The following items need to be included in a detailed cost estimate summary:

1. Technical and Operational Concept Description: Based on the CADRe or Technical baseline, including brief summaries of information including technical, schedules (project schedules and Systems Engineering Master Schedule), and acquisition strategy.
2. Methodology and Models: Identify the basis for using a particular method and model for primary and secondary estimates. For each model used, include all details involving parametric input or output including adjustments. Data used to calibrate CERs should be documented here.
3. Cost Estimate: To include definitions of the cost elements, a description of how the cost was derived, definition of input variables, list of values assigned to input variable, mathematical formulas used, list of cost factor drivers per cost element, and data sources, data obtained, and adjustments made to the data. This section should show the estimate by including any sunk costs (actuals) and then the remaining life cycle costs by phase. New facilities, initial spares and other start up investment costs as well as operations costs (and operational scenarios) should be included for a full life cycle cost estimate. Inflation, present value and any other supporting assumptions should be included.
4. Risk Assessment: To include the range of costs, either by utilizing statistics or expert opinion. The use of a random (+/-) is not sufficient. A cost S-Curve generated through a documented cost risk assessment and a reserves sufficiency analysis are most appropriate.
5. Cost Drivers: To include the key drivers that focus on performance, reliability, maintainability, and general operations should be included. Each driver should be looked at independently as well as in likely combinations.
6. Sensitivity Analysis: Should focus on the cost changes due to movements within the operating parameters. As with risk assessment, a random (+/-) will not suffice. If numerical analysis isn't possible, qualitative analysis should be performed. Results should be given in such a manner that it focuses attention on the cost impact for each element within the system.

Task 11: Present / Brief Results

While it may not be realistic to standardize the content and format of the cost estimating briefing charts across all NASA Centers for all estimate types, an objective of this task is to promote the quality of the cost estimating and analysis documentation by advocating consistency across and in Centers.

There are three activities associated with presenting/briefing results:

1. Create briefing materials and supporting documentation to be used for internal and external presentations as appropriate. (See Appendix H)

2. Present and defend the estimate.
3. Gather from customers and provide feedback to capture improvements for the next estimate. (See Appendix BB for a sample Customer Feedback form).

While it may not be realistic to standardize the content and format of the cost estimating briefing charts across all NASA Centers for all estimate types, consistency across and in Centers facilitates understanding during the management review process and promotes completeness and quality of the cost estimating and analysis documentation. A template for the first five pages for a standard cost estimate briefing at NASA has been provided for download at ceh.nasa.gov. A summary of this template and its use has been provided in Appendix H. Estimators are encouraged to use this template for all estimate briefings to increase consistency, decision maker familiarity, and comfort with the template and in the long run to build credibility in estimate presentations at all levels at NASA.

Cost estimates are used as baseline rationale to develop budget submissions for Presidential and Congressional approval. A budget is partly subjective; to increase the validity of requested dollars, a program that uses a valid cost estimate greatly improves the defensibility of a budget request.

The cost estimator should prepare briefing material and supporting documentation to be used for internal and external presentations as appropriate. It is again recommended that each Center maintain as much consistency internally as to the data format as possible since this facilitates understanding during the management review process and promotes completeness and quality of the cost estimating and analysis documentation by using the provided template. Thorough documentation is essential for a valid and defensible cost estimate. Cost presentation documentation provides a concise, focused illustration of key points that should direct the reader's attention to the cost drivers and cost results.

Task 12: Update Cost Estimates on a Regular Basis

The purpose of updating the cost estimate is to defend the estimate over time, to reduce updated estimate turn-around time, and to give decision-makers a clearer picture for major decisions or “what if” drills.

There are two activities associated with updating the cost estimate on a regular basis.

1. Obtain and assess customer feedback and conduct a lessons learned analysis upon estimate completion and incorporate this feedback to the next version of the estimate.
2. Update estimate when project content changes and as the project moves through its life cycle phases and conducts milestone reviews.

Cost estimates must be updated whenever project content changes and reconciled to the estimate baseline. By accomplishing a cost estimate on proposed program alternatives, the Project Office can determine the cost impact of the alternatives.

Cost Estimating Considerations By Project Life Cycle Phases

In this section, the twelve tasks in the cost estimating process are described in relationship to each of the six phases of the project life cycle. This section focuses on high-level information in the context of the process. Details about how to conduct each task within the cost estimating process are provided in the previous section. Exhibit 4-1 illustrates that the life cycle phase influences the type of estimate required and which organizations get involved. In this section, the overall objectives, issues and challenges, roles and responsibilities, and exit criteria for each of the six NASA life cycle phases are described. As shown in the Exhibit, the CRL can be influenced by the project life cycle phase.

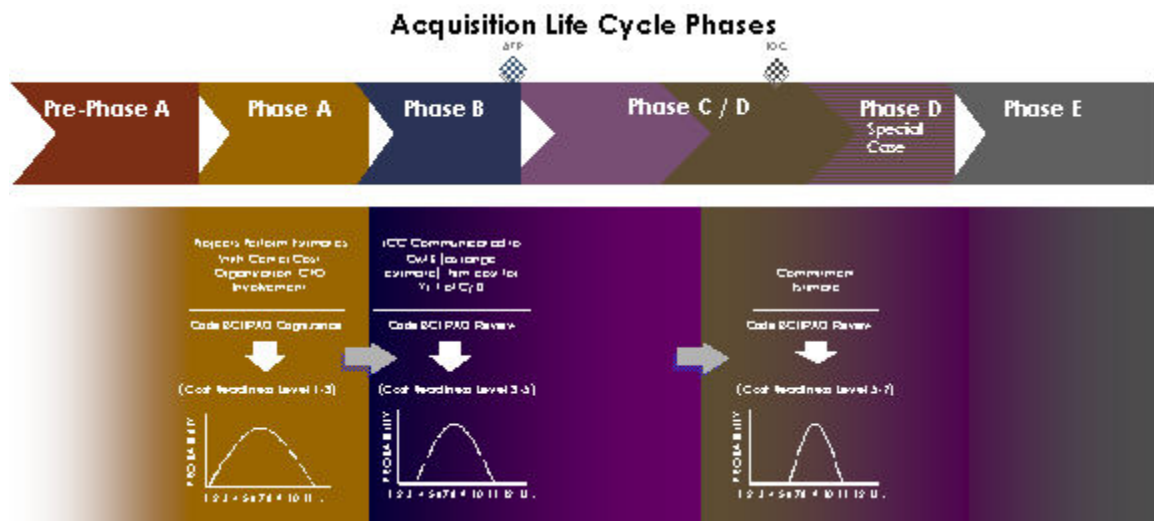
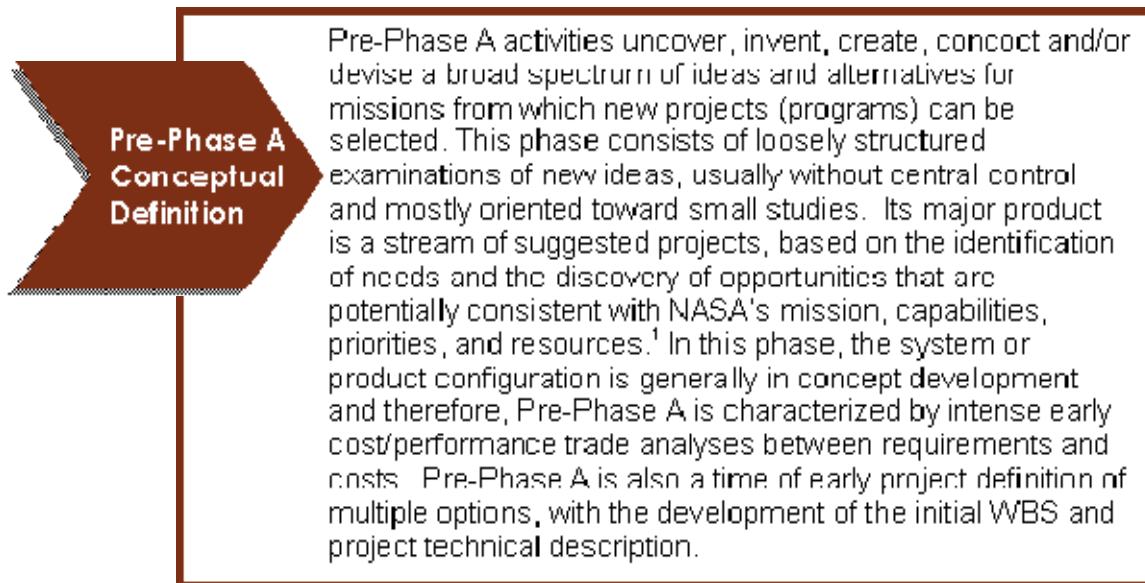


Exhibit 4-1: Life Cycle Influence

Pre-Phase A



Pre-Phase A Overall Objectives

Investments need to contribute directly to an organization successfully meeting its mission. Working closely with the project technical staff to examine the costs, benefits, and risks associated with making an investment, the overall objectives in Pre-Phase A are to determine the best solution to meet NASA's mission, goals, and objectives within its cost, technical performance, and risk tolerance baselines. This is done by conducting and analyzing ROM LCC estimates, by establishing performance metrics, and by analyzing benefits and risks. At this phase, a ROM estimate(s) should be sufficient for planning purposes, including budgeting, and more responsive to the PM, who does not have the resources or time to develop a precise estimate that might not even be possible given the number of assumptions and uncertainties associated with this phase. The cost estimator must also work with the PM to establish the cost risk margin(s) that are broad enough in range to account for the level of uncertainty and to ensure that the CRL reflects this uncertainty. Establishing the estimate's CRL during this period is critical in communicating the maturity of the estimate to decision makers.

Pre-Phase A Roles and Responsibilities

Pre-Phase A Issues/Challenges

The following list describes some of the issues and challenges faced by NASA cost estimator during this life cycle phase:

- ▶ Variable and early definition of requirements.
- ▶ Project content not fully captured and reflected in cost estimate (e.g., ground systems, software, etc.)
- ▶ Optimism in schedule, technology and acquisition strategy planning.
- ▶ Not fully accounting for the risks.



The role for the cost estimator in Pre-Phase A is to understand the key engineering performance parameters (KEPPs)^[1] so as to develop ROM cost estimates (ranges preferred) for different levels of KEPP expectations. The concept developer,

ordinarily within a Performing Center, begins developing a concept using a core team including designated cost personnel from Supporting Centers as required. The resulting concept will be submitted to the NASA Enterprise Office for review. Funding estimates are generated parametrically, using aircraft and historical space data, and tools such as NAFCOM, PRICE, and SEER^[2]. The funding estimate often will be part of a submission of a technology or idea that supports the space launch portion of the NASA Strategic Plan. If acceptable to the NASA EAA and CFO, a NASA project is initiated using a Program Formulation Agreement (PFA). The PFA establishes, among other things, resource estimates, cost risks, contingency reserves, and related relevant requirements. The funding estimates become part of the 5-year budget cycle, and identify program-funding levels for the budget year two years out.

- ▶ Over-optimism in hardware/software reuse.
- ▶ Going external with cost too early or without a correctly specified CRL.

The cost team working with the project is responsible for preliminary cost estimates and cost support for conceptual design activities. The Enterprise, IPAO, and PA&E will primarily maintain cognizance in Pre-Phase A with PA&E providing strategic guidance for cost estimating processes to include assessment of risk for cost impacts.

Pre-Phase A Exit Criteria

The decision to proceed into Phase A will be made on the basis of technical feasibility, desirability, and affordability of the ideas derived from these early concept definition trade studies and cost estimates. In-house estimate reviews are conducted at the discretion of the Project Office, and may include review of prime hardware contractor input. Each major concept update requires an acceptance decision. Each review of data prior to a NAR requires PM acceptance of cost as part of the whole concept. The PM must take into account overall budget constraints, cost, schedule, and technical risk, and cost realism, reviewed as one requirement of the overall design requirements. These PM reviews are the key to successful concept selection and success at the NAR/project approval reviews

Phase A / PrePhase A Design Concept

Phase A further examines the feasibility and desirability of a suggested new major system or project before seeking significant funding. NASA personnel must work to ensure that data required will be available to *manage* to the estimate that supports the budget, keeping in mind that the CRL calculated-regardless of the risk reserve established through the cost risk assessment. During this phase, these risk reserves should be revisited and potentially the ranges refined (i.e., narrowed). This Phase is where the Project is beginning to identify cost drivers in terms of risk ranges. The final cost/performance trade studies from the end of Pre-Phase A represent the beginning of its full implementation. Phase A continues to be a time of intense design formalization and documentation.

Phase A Overall Objectives

Phase A estimates are conducted for many purposes. A Pre-NAR and an ICE are required and a project estimate is used not only as the baseline project estimate, but also as the basis of estimate for the project's budget. Project Managers use cost estimates as baseline rationale to develop budget submissions for Presidential and Congressional approval. As a budget is partly subjective; to increase the validity of requested dollars, a project that uses a valid cost estimate greatly improves the defensibility of a budget request. This is because with a detailed cost estimate, there is little room for hiding money or for asking for too much. Similarly, a detailed cost estimate will show impacts to the project if allocated too little money. Quality, risk, and sensitivity analyses along with thorough documentation and a consistent briefing format are all important factors when defending an estimate.

An overall objective in this phase is to secure funding for the project, which requires an understanding of the project's business drivers and sound business decision-making. To do this, the cost estimator must re-examine the cost, risk, and performance parameters to ensure that they accurately reflect the system as it is being designed. While most RFP and contract work is an activity in Phase B, some of this data may be available in Phase A to begin.



Phase A Roles and Responsibilities

Phase A Issues/Challenges

During Phase A, Centers define an affordable concept and expand the goals and objectives into a set of requirements and implementation options, available technology, risks, budget, and schedule are identified and investigated. In this phase, cost estimators examine cost feasibility, uncertainty, and constraints. Later in this phase, feasible concepts are studied and trade studies are performed to determine an optimal concept. After alternative concepts have been analyzed, the project is defined, approval received from the governing PMC, and 1-2 primary concepts are chosen for further development and project planning.

If a CADRe is required for the Project, the contractor and/or NASA project engineers, assisted by cost estimators, construct the NASA Project CADRe. A NASA CADRe is required for all projects. An abbreviated NASA CADRe may be appropriate for lower category or early phase estimates. The Project CADRe provides the technical basis for the LCCE and, for Category I projects, supports the Congressional requirement for an ICE prior to entry into Phase B. Cost Analysis Division and the IPAO will coordinate on this ICE, which will be communicated as preliminary and presented as a range of possible costs that are clearly subject to change. A full NASA CADRe is required for entry into Phase C to support the Phase C ICE and project LCCE, whose cost ranges should be greatly reduced from the Phase B ICE and project LCCE.

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- ▶ Inadequate understanding of reserve needs; lack of cost/schedule/technical risk knowledge.
- ▶ Untenable schedules.
- ▶ Over-optimism in project and contractor capabilities, technology, and execution plans.
- ▶ Over-subscription to management reforms or new ways of doing business.
- ▶ Tendency to influence or accept contractor buy-in.
- ▶ Lack of independent validation of costs/schedules.

Mission Directorates identify ICE applicable projects early in a FY (e.g., >\$ 150M). An ICE is integrated into IPAO reviews and during the process, Cost Analysis Division assigns a cost team drawn as appropriate from Cost Analysis Division, IPAO, and the Center. The team may also draw upon Center cost organizations, support contractors, Federally Funded Research and Development Centers (FFRDCs), and consultants. The review team reports to the governing PMC and then the Cost Analysis Division works with the Office of Legislative Affairs to draft the Congressional report. For Category I projects, the Project LCCE, based on the technical requirements defined in the NASA CADRe, is first developed by the project and coordinated between the project and the Center Independent Review Organization or Center cost group near the end of Phase A. In some cases a separate, and additional estimate is developed by the Mission Directorate as a crosscheck that also becomes part of the coordination. At the same time, the IPAO develops an ICE, based on the same Project CADRe, with Cost Analysis Division cognizance. A coordination meeting, chaired by Cost Analysis Division/Office of the Chief Engineer, presents the Project/Center Independent Review Organization/Mission Directorate LCCE and the IPAO ICE to coordinate on the two positions. A period of 30 days is allotted for full coordination/reconciliation between both cost positions. In the unlikely event of irreconcilable differences between the estimates, a pre-Agency PMC (APMC) reconciliation review is held, chaired by Office of the Chief Engineer/Office of the Chief Financial Officer to formulate a recommended cost position to the APMC.



Phase A Exit Criteria

There are two primary categories of cost review during conceptual design. The first type is an internal PM review of the contractor and in-house (or advocate) estimates. The second type of review is the external pre-NAR or at some Centers, an Independent Assessment (IA). For the space launch programs, one NAR occurs early in formulation on advanced concept review. This is done after basic program documents such as the project plan and a draft Systems Concept Document are developed. This pre-NAR is part of the preliminary program approval review performed by the PMC.

The PM's estimate is reviewed externally against an ICE, developed outside the project by the IPAO using the same CADRe as a technical baseline. The focus, or criteria, for the review is the thoroughness and realism of the cost estimate including estimated reserve requirements. Exit criteria include:

- ▶ All cost estimates done in full cost.
- ▶ A minimum of a preliminary CADRe exists in late Phase A for any category project.
- ▶ All WBS items are costed (no TBDs).
- ▶ A preliminary Cost Analysis Division/IPAO ICE at end of Phase A for projects with expected LCC > \$250M.
 - OMB-provided first year of implementation funding; out years as ranges;
 - CRLs calculated, documented, and clearly communicated;
 - Probabilistic cost/schedule risk range across multiple configurations/design solutions;
 - Outyear cost expressed in ranges are desired, but in many cases it will only be possible to provide discrete values.
 - At Confirmation Reviews and Authority to Proceed (ATP) decision point, the cost estimate must include an appropriately chosen level of reserves.

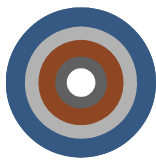
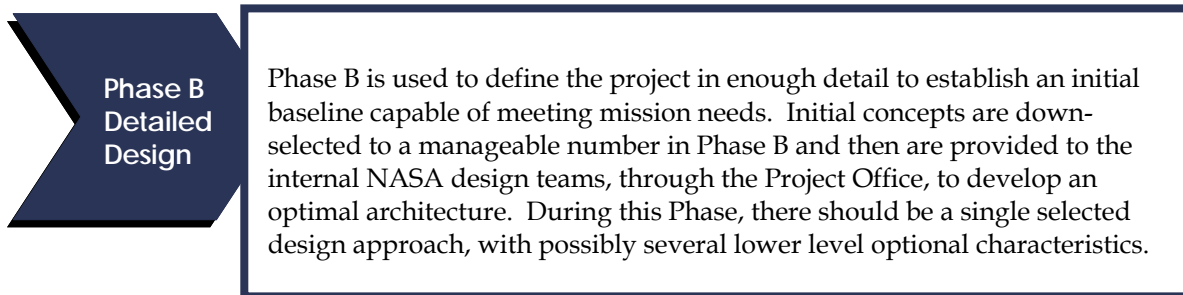
The PM must correct estimating problems, questions, and issues identified by the NAR team and the PMC. If the cost estimate must be revised, the iterative cost/design process, discussed in the estimate refinement section, is used and the updated estimate provided to the Project Office and the PMC. In Phase A, the PM should review estimates for approval/disapproval based as a minimum on the following criteria:

- ▶ Affordability: Ensure that the cost estimate indicates that the candidate system is affordable based on the affordability estimate and preliminary budget data from NASA. To determine this, the PM must review the estimate to ensure it is compatible with the budget. An estimate/budget reconciliation and an understanding of any disconnects is helpful at this stage. The PM should be aware that a primary difficulty in cost estimation in this early stage is decision-maker demand for unrealistic precision that is above the state-of-the-art given concept definition fidelity. Clearly defining the decision criteria and demonstrating that the precision available supports those criteria may mitigate this difficulty.
- ▶ Realism: The probability that the cost estimate is within a realistic range. This requires that the level of precision be such that the cost estimates are representative of the expected value and consistent relative to other options. A high-level cost risk assessment is also important at this point, based on the technical risk assessment already documented in the technical baseline or the Phase A CADRe, schedule analysis, and cost risks. Ensure that the 'typical' cost drivers are identified as well as the magnitude of the risk that they represent. This will allow the PM to identify estimates that are unrealistically optimistic in areas such as technology assessment, schedule, or general support requirements. At

this point it is also recommended that a cross check estimate be conducted, either using a different estimating methodology, or at a minimum, using a different cost model to help reveal any issues or items that may have been overlooked or not fully understood in the estimate.

- ▶ Sufficient Detail: Ensure the cost estimate is completed at the level and precision needed to influence the current stage of the design. Has the estimate identified the cost drivers in the system, and does the estimate adequately address these drivers? Early estimates should reflect the nature of decisions being made at an early stage, and need only distinguish between early level alternatives.

Phase B



Phase B Overall Objectives

During this phase, an objective for the cost estimator is to refine the point estimate's accuracy by scrutinizing the assumptions, the cost drivers, risks, and conducting periodic PRAs. During this phase, more specific data is available to develop a solid technical baseline or NASA CADRe, conduct a full LCCE, and reconcile it with a NAR. Estimates should be based on preliminary design review (PDR) or near PDR quality definition. The maturity of the data and the better-defined project should also help improve the CRL for each of the estimates. In Phase B, the numbers of concepts are down-selected to a manageable number from which the internal NASA design teams, through the Program Office, develop an optimal architecture. During this Phase, there should be a single selected approach possibly with several lower level optional characteristics.

Phase B Issues/Challenges

Cost/schedule risk analysis should be driven by PRA-identified risks plus programmatic and management risks. A contractor estimate(s) is often developed separately and the various estimates compared for completeness, standardized GR&A, and reasonableness. At this Phase, a CADRe is required and there is also a NAR reviewed and adjusted cost estimate.



Phase B Roles and Responsibilities

The role of the cost estimator during this phase is critical. It is important to understand the basis of the estimate, from the technical baseline to the cost risk assessment and to be able to document and present the results of these efforts to the decision makers. Findings during this phase for cost, performance trades, and risks influence the acquisition of a system and the execution of the project. It is the cost estimator's responsibility to test, understand, and validate the knowledge base used to derive estimates. It is also the responsibility of the cost estimator to ensure the best possible LCCE with recommended reserves based on updated cost risk assessments in Phase B. These estimates will support budget formulation as well as source selection support in the transition from Phase B to Phase C/D. The cost estimator ensures that the NASA CADRe used as the basis for the estimate is as complete and accurate as possible and that it is the same version that the project LCC team and the NAR team uses to build their estimates. In this phase, another critical responsibility of the cost estimator is to work with the PM and acquisition team to ensure that solid WBS reporting structures and data collection mechanisms for the execution of the project are in place.

Making this process more efficient, NASA has established a program of cooperative engineering centers called PDCs. At these centers, the engineers and cost analysts determine the relative benefit of specific technologies or mission concepts to improve space transportation or the mission using individual workstations and the variety of analysis tools. Center and visiting/teleconferenced experts analyze all aspects of a space project, from the technical aspects of flight operations to a business model to determine the ROI. The PDCs enable cost personnel to rapidly estimate costs for a variety of concepts. As the program or project matures during the formulation sub-process, concept definition designs are refined and their number reduced, with more detail being added to the cost estimate. The earlier concept definition tools are generally phased out and engineering expertise and actual data are used more frequently.

The office responsible for building these concept cost estimates, particularly the Design Development (DD) estimate, is the cognizant cost office at the performing Center, using tools like NAFCOM, the PRICE estimating suite, and SEER. Operations and Support (O&S) estimates are generated using a different set of tools such as MESSOC, SOCM, RMAT, COMET/OCM, GEM-

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- ▶ Trying to overcome the lack of cost/schedule/technical risk knowledge, to be able to defend reserves as demonstrated by the evolving nature of a Project.
- ▶ Unrealistic schedule constraints due to corporate or contractor commitments.
- ▶ Over-optimism in project and contractor capabilities, technology, and execution plans.
- ▶ Over-subscription to management reforms or new ways of doing business.
- ▶ Tendency to influence or accept contractor buy-in as RFP release approaches.
- ▶ Independent validation of costs/schedules may lead to new issues to be reconciled and resolved before proceeding according to schedule.

FLO for cycle time, and Architectural Assessment Tools-enhanced (AATe)^{1[1]}. Supporting NASA centers provide cost data input in such areas as spaceport operations (Kennedy Space Center), mission operations and data analysis (Goddard Space Flight Center and Jet Propulsion Laboratory), and airframes (Langley Research Center). Together, these cost analysts work to build a concept architecture. In some cases, they study the impact of infusing new technology into a reference vehicle and its impact on cost. In many cases, they study concepts initially generated by contractors, then selected by the PM for cost, schedule, and technical merit.



Phase B Exit Criteria

Throughout the process, cost personnel support a variety of reviews. PMs may specify internal reviews, in addition to the required NAR required to move a project into the implementation process. These reviews ensure the concept being developed meets NASA resourcing goals and objectives for the project, among other requirements. Towards the end of project design phases (Pre-Phase A, A, and B), as system requirements are sufficiently developed, the project prepares for a Project Approval Review by the Center PMC, usually in concert with the NAR. Part of this review includes an ICE, performed by a cost estimation office outside of the performing Center. The Phase A independent LCC estimate is reviewed, including funding resource requirements, reserve allocations, workforce and infrastructure requirements, and partnering efforts. Contractor estimates and the ICE are reviewed, differences analyzed, and potentially reconciled, by the cost office. Subsequently, one, or a combination of the cost estimates, is presented by the PM during the project approval process to the assigned PMC. If costs are accepted, the estimates become part of the overall approval process to move the system to implementation. If estimates are not satisfactory, they are returned to the cost office for additional estimation and analysis.

The PM should review estimates for approval/disapproval and reconciliation based as a minimum on the following criteria:

- ▶ Ensure the cost estimate is comparable to other estimates, notably the ICE, and between the various contractor estimates. The reason for major differences between estimates should be clearly understood and explained as part of the reconciliation and review.
- ▶ Ensure the cost estimate has a detailed cost risk assessment that is documented in the estimate documentation and supporting risk data is detailed in the CADRe. At this point, the areas of cost risk addressed earlier should have been mitigated or reduced to a manageable level, and this reduction documented and reflected in the estimate. This does not mean that the cost estimator has ignored cost realism and removed or minimized the risks and their impact. It means that the cost estimator has worked with the technical team to identify, understand, and document trade studies, alternatives, and risk mitigation strategies and this risk mitigation is realistically reflected in the cost estimate.
- ▶ Verify the full cost aspects of the estimate.
- ▶ Ensure the estimate meets NAR requirements, to include funding resource requirements, reserve allocations, workforce, and infrastructure requirements, risk assessment, and external contributions such as partnering.

A successful late Phase B review moves the project, including its associated cost estimate, into the Detailed Design and Development Phase C/D, and out of the Preliminary Design Phase B. Exit criteria guidelines include:

- ▶ NASA CADRe or abbreviated CADRe in late Phase B depending on project category.

- ▶ IPAO/Cost Analysis Division ICE based on increased detail (eventually major assembly, component level).
- ▶ Probabilistic cost/schedule risk analysis (tied to PRA identified risks) plus programmatic and management risks.
- ▶ Updated cost/performance trade/CAIV study (ies).
- ▶ Field Center, Mission Directorate and Cost Analysis Division reconcile to one probabilistic estimate for PMC.

Phase CD

Phase C establishes a complete design ("build-to" baseline) that is ready to fabricate (or code), integrate, and verify. During this phase, technical parameters, schedules, and budgets are closely tracked to ensure that undesirable trends (such as an

unexpected growth in spacecraft mass or increase in its cost) are recognized early enough to take corrective action. As the project proceeds through design, development, and test and evaluation, the project technical description/NASA CADRe is updated as necessary to reflect major engineering and requirements changes. Updates to the reference point estimate, risk assessment, and cost-risk impacts, and CRL are made and reflected in new cost-risk distributions.

Cost trend data captured in the EVMS is an input to these LCCE updates since there is much to be gained from exploiting the cost, risk, and cost-risk knowledge captured via EVM and possibly IFM during development for improving cost and cost-risk databases, cost models and, ultimately, estimates on future projects.

Phase D builds and verifies the system designed in the previous phase, deploys it, and prepares for operations. Subsystems (including the operations system) are built and integrated to create the system. As the project completes design, development, test and evaluation and proceeds to production, the project technical description/NASA CADRe is updated as necessary to reflect final engineering decisions along with associated updates to the reference point estimate (in conjunction with the EVM specialists tracking the cost trends in the Cost Performance Reports (CPRs), risk assessments, and cost-risk impacts. Since the end of Phase D represents the completion of project development, this is the most critical phase to capture the cost, risk, and cost-risk knowledge captured via EVM, possibly IFM and actual cost data along with final development phase technical parameters in the CADRe. This documentation will help improve cost and cost-risk databases, cost models and, ultimately, future project estimates.

Design changes continue to be an iterative process in this Phase, with cost estimates analyzed for affordability and effectiveness at each design change. Estimates are based on CDR/ near CDR quality definition and new estimates include estimates of major engineering changes. These should be integrated with EVMS by this Phase and processes for capturing cost analysis knowledge should also be in place to improve cost model accuracy. Some of these processes are contractor cost data collection requirements integrated into EVM, civil service cost data collection requirements integrated into IFM, and prime contractor special cost analysis DRs still required for other cost data requirements such as heritage of parts/software and other information.



Phase C/D Design, Development Test and Evaluation (DDT&E)

Phase C/D Overall Objectives

The connection between the Definition and the Design phases of an investment's life cycle is critical to maintain in order to realize estimated benefits and stay within estimated costs. Cost/performance trade studies are ongoing in this phase and updated periodically. In addition to creating the foundation for certain plans, the benefits and their definitions should be considered. THE performance metrics and targets for the on-going evaluation of the investment. It is only logical that the criteria against which the investment was assessed would be the same as the criteria against which the performance of that investment is tracked and assessed through test and evaluation. The cost estimator, in developing the costs for these trades, plays a key role in this crucial assessment.

Phase C/D Roles and Responsibilities

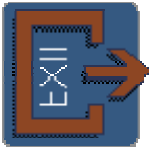
The cost estimator's role in Phase C/D is to review the engineering build up estimate for reasonableness, completeness, and consistency with the project's GR&A. It is also the cost estimator's responsibility to test, understand, and validate the knowledge base used to derive engineering build up estimates. It is important for the estimator to understand his/her role in supporting the cost management phase of a project and how his/her updated estimates, actual cost data, and documentation can assist the PM. It is also important for the cost estimator to recognize his/her responsibility in capturing data from this phase of the Project to benefit future efforts. If actual cost data is captured and documented in a methodical manner, data collection after the program ends and during its execution is much easier and ensures that the data is more reliable.

While it is not as common for the estimator to be involved in Phase D estimates, it is becoming increasingly important. Costs and risks from the early phases of a project should have been captured and documented as actuals in the estimate to date. It is important for the cost estimator to ensure this data is reflected in the program LCCE. It is important to capture the data for the immediate project estimates and as data for estimating the costs of future projects.

Phase C/D Issues/Challenges

The following list describes some of the issues and challenges that the NASA cost estimator faces during this life cycle phase:

- ▶ Basic requirements changes.
- ▶ Make-it-work changes.
- ▶ Inadequate risk mitigation.
- ▶ Integration and test difficulties.
- ▶ Reluctance to reduce headcounts after peak.
- ▶ Inadequate insight/oversight.
- ▶ Lack of understanding or poor use of EVM and schedule analysis as an effective early warning capability.
- ▶ De-scoping science and/or operability features to reduce nonrecurring cost:
 - Contract and design changes between the Development and Operations phases;
 - Reassessing cost estimates and cost phasing due to funding instability and stretch outs; and
 - Development difficulties.
- ▶ Manufacturing breaks.



Phase C/D Exit Criteria

Reviews at this Phase with Office of the Chief Engineer/Cost Analysis Division involvement and the governing PMCs are designed to minimize duplication with other reports and organizations involved. These reviews ensure the concept being tested and deployed meets NASA re-sourcing goals and objectives for the project, among other requirements. Phase C/D estimates involve project surveillance and estimates of any new or modified concepts. If costs are accepted, the estimates become part of the overall approval process to move the system to operations. If estimates are not satisfactory, they are returned to the cost office for additional estimation and analysis. Exit criteria include:

- ▶ Estimates of major engineering changes (in cooperation with EVM community).
- ▶ Estimates if project re-baselines.
- ▶ Improved processes for capturing cost estimating knowledge for future cost models.
- ▶ Using NASA CADRe and augment via EVM and possibly IFM

Special Case: Phase D (Production)

In the unusual case at NASA that more than one unit of a system is produced (e.g., reusable launch vehicles, multiple TDRSs, etc.), the Project enters Special Case Phase D. For the most part, the tasks followed in Phase C/D should also be followed in Special Case Phase D, Production. For example, both the WBS and CADRe should be updated to prepare for updates to the reference point cost estimate, risk assessment, and “S”-curve. Also, the CRL should be updated in the cost estimate documentation.

In the unusual case at NASA that more than one unit of a system is produced (e.g., reusable launch vehicles, multiple TDRSs, etc.), the Project enters Special Case Phase D. For the most part, the tasks followed in Phase C/D should also be followed in Special Case Phase D, Production.

For example, both the WBS and CADRe should be updated to prepare for updates to the reference point cost estimate, risk assessment, and “S”-curve. Also, the CRL should be updated in the cost estimate documentation.

Phase D Special Case Production

Cost estimates in Phase D still focus on major engineering changes (in cooperation with EVM community) and estimates if project re-baselines. Reviews and cross check estimates are conducted at the end of Phase D to evaluate production costs and readiness to move to operations and support in Phase E. During special case Phase D, it is important for the estimator to focus on using improved processes for capturing cost estimating knowledge for future cost models as production runs at NASA are not common on all Projects. Using the NASA CADRe data and augmenting it with EVM and possibly IFM data is important for collecting actuals for future Projects.

Phase E

Phase E

- ➡ Operations, Support &
- ➡ Disposal

Phase E is the final phase of a Project. As a Project proceeds to the Operations, Support & Disposal phase, the project technical description or CADRe is updated as necessary to reflect final engineering decisions along with associated updates to the reference point estimate (in conjunction with the EVM specialists tracking the cost trends in the CPRs), risk assessments, and cost-risk impacts.

The connection between the DDT&E and the Operations, Support & Disposal phases of an investment's life cycle is critical to maintain to realize estimated benefits and capture actual data during operations. Actual cost data can also benefit future projects by using the performance metrics and targets from the current project evaluation and cost growth lessons learned. Collecting and sharing O&S data is helpful as there is very little O&S data available to estimators.



Phase E Overall Objectives

The overall objective of Phase E is to support, maintain, and at the appropriate time, dispose of the system. Cost estimators may be asked to conduct Estimates at Completion (EACs) at the beginning of this Phase and should be available to the Project team for analyzing project cost data for use in follow on projects. Costs and risks from the early phases of a project should have been captured and documented as actuals in the estimate to date. The costs of O&S are often overlooked when capturing actuals for comparisons to estimates.



Phase E Roles and Responsibilities

This is an excellent time for the estimator to reconcile previous estimates to the current actuals and calibrate estimating methods from the initial estimates. It is important for the cost estimator to ensure this data is accurately captured and reflected in the program LCCE and stored for future projects in ONCE. If the actual cost data is captured and documented in a methodical manner during O&S, it makes the effort of data collection after the project ends much easier and ensures that the data is reliable.

Phase E Issues/Challenges

The following list describes some of the issues and challenges faced by NASA cost estimator during this life cycle phase:

- Little involvement in the project due to minimal requirements for estimate updates.
- Limited access to data for future use.

- Important phase for data capture for use on future programs to reflect accurate O&S costs and an overview of the entire Project costs.



Phase E Exit Criteria

Exit criteria for a Project from Phase E leads to Project closure. This exit criteria is not based on a cost estimate, but rather a measure of success for the Project objectives, cost data captured, cleanup, and disposal. For a cost estimator, the most important criteria is estimate reconciliation and archiving actual data for future estimates. Some of the key criteria for Project exit from Phase E include:

- Project has been fully operational and supported through its expected life.
- Project is disposed of as planned.
- All actual data and cost estimating knowledge is captured for future cost models.
- The project and the cost estimating team reconcile estimates at completion (EAC) with cost/performance data and document lessons learned

Phase E Special Considerations

Estimating costs for the operational phase of complex aerospace programs, especially using full cost, presents unique challenges. Difficulties include:

- Inadequate data / information technology (I/T) systems during operational phases for relating labor, materials and activity functions to flight and ground system designs. Project and program management needs for project controls, such as budget insight and controls (such as grass roots estimates, bottoms up processes) may not match the type of data nor systems required to provide linkages of design decisions to operational costs. The later type data collection and I/T systems are an easy target in project cost cutting efforts. This hobbles the prediction and understanding that can be applied from real world experience to future systems.
- Uniqueness of end items, meaning that when data is available it is sparse as regards drawing cost estimating relationships that would otherwise be reinforced or confirmed by more data points, as with similar systems for similar environments. This again hobbles the prediction and understanding that can be applied from real world experience to future systems.
- Low flight rates, such that operating data that is available (failures, costs, delays, processes) associated with the operation, maintenance, logistics, sustaining engineering, work control, management and infrastructure upkeep and operation, does not approach a quantity of quality data that would easily identify drivers or bottlenecks. When every data point has unique circumstances and derives from a process with high variation, the conclusions drawn from such data, even after filtering and cleanup, can significantly

introduce uncertainty. This again hobbles the prediction and understanding that can be applied from real world experience to future systems.

- Operations, as it lies many years in the future in aerospace systems, during a Phase A/B of a project, receives far less weighting in decision makers minds, than the near term job of design, development, test and engineering. As a result, the type of information required for a credible operations cost estimate, though it may exist in Phase A/B, does not flow as easily to the cost estimators. It is not a priority, and its gathering and organization in a format usable for an operations estimate may be seen as a distraction from the organization and handling of that information relevant to near term tasks.

Promising approaches to overcoming such obstacles can be accomplished by various strategies both technical and non-technical such as:

- Development of electronic data interchange formats, databases, or ontologies that ease the use and reuse of product description data by all stakeholders, from program and project management, to design and manufacturing, to cost estimators, including those looking to operations years ahead. As of 2006 The NASA Exploration initiative has such an approach in practice referred to as NExIOM or NASA Exploration Information Ontology Model.
- Establishment, management support, and continuous capability development for such corporate knowledge as organizations sufficiently long lived to gather data across programs, studies and recurring organizational restructurings. Such capability should be refreshed as needed with operational experience, new-hires and institutional succession planning, and dedicated cost estimators.
- Over-communication on estimation methods, rationale, logic, calculations, limitations of data, implications of such to the estimate, best and worse case analysis, and operations drivers, to overcome both the data adequacy issues as well as the perceived lesser importance of a cost not yet to be incurred for many years. Operations are a cost to be inherited by a decision maker/manager that is often NOT the one deciding the emphasis on understanding such estimates in the near term. Communication is key. Estimates must withstand sanity checks.

Lastly, not all operations cost estimation exists in a vacuum from other key systems engineering factors. Although not as easily measurable, it is often the responsibility of the operations cost estimator to highlight related factors that should feed into decision making, or cost estimators recommendations. For example, as witnessed in the Columbia Accident Investigation Board (CAIB) report a sub-system (such as thermal protection systems) may receive organizational attention only as a maintenance issue, with an accepted, well understood, known turn-around cost. Regardless, costs perspectives must not neglect to seek out and integrate with systems engineering perspectives or that of other areas such as risk covered elsewhere in this handbook.